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RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF

N.V. PHILIPS' GLOEILAMPENFABRIEKEN

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PROPERTIES AND APPLICATIONS OF ARTIFICIAL RESIN PRODUCTS

By R. HOUWINK.

Summary. The chemical nature of artificial resins is briefly outlined with the principles on which their manufacture is based. As artificial resins are *per se* electrical insulating materials, this property is compared with that for other insulators; the differences between "Philite" and other insulators are also referred to. Various applications of "Philite" resins are then enumerated and discussed, followed by reference to products with special properties designed to meet the specific requirements of the consumer.

Introduction

The progressive development and expansion of the electrical industry has led to an increasing demand for cheaper and better raw materials. That the demand has not by any means been met is shown by the call for materials with low dielectric losses (low values of $\tan \delta$), which during recent years has become very heavy in view of developments in short-wave technology. The demand is not merely for an insulating material *per se*, for the material required has also to meet a host of other requirements. For example a material, such as mica, which has an exceptional suitability for making certain articles is yet frequently found useless in mass production as soon as it becomes a question of making units of complicated shape by an inexpensive process and which have to be within close dimensional tolerances. It may be noted that these requirements present insulating technology with entirely new problems, especially as the consumer is not merely concerned with the insulating properties and the mechanical strength, but frequently makes a point of specifying a pleasing appearance, which can only be obtained by very complex and highly perfected finishing processes.

In this article we will show that one of the chief reasons why "Philite", an artificial resin, which can be readily shaped by hot pressing, has found extensive applications is mainly because it can satisfy a host of practical requirements at one and the same time. Fig. 1 shows

a selection of "Philite" products, and brings out the wide variety of objects into which this material can be moulded and for which it can be utilised.



Fig. 1. Various "Philite" products for technical uses.

Basis of Manufacture of Artificial Resin

Even twenty years ago resinified products obtained by chemical reaction were disposed of as useless waste. At the present time the exact reverse is the case, and in a large number of industrial laboratories systematic search is proceeding for still further artificial resins. Of the great variety of artificial resins which have been evolved in recent years, consideration will be

limited here to the phenol-formaldehyde resins, since these form important constituents of various types of Philite materials. It would lead too far to discuss in detail the chemistry of these resins, although an attempt will be made with the aid of *fig. 2* to explain the fundamental principles on which the formation of such a resin is based. If

artificial resin filling every corner of the matrix or mould. If the body is kept at this high temperature for a few minutes longer the hardening process already referred to takes place, with the result that the mass hardens in the mould and can therefore be removed from the warm mould without the latter having to be cooled.

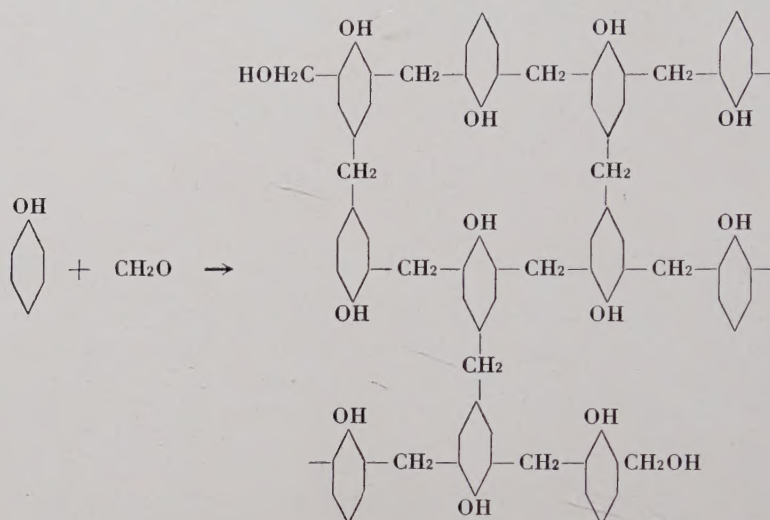


Fig. 2. Formation of phenol-formaldehyde resin. This method of representation is purely diagrammatic. The benzene nuclei must be regarded as arranged specially and linked to one another in some sort of haphazard arrangement, without giving a "pattern" as indicated in this figure.

phenol and formaldehyde are caused to interact at a high temperature, then as shown in *fig. 2*, the molecules of these bodies combine to form a reaction product which in the figure is denoted by the word "resin". It is seen that by condensation a very large molecule is produced, and the assumption is justified that a pressed product of artificial resin (apart from fillers, which for various reasons must be added) consists of a single large molecule. This gradual growth to a so-called macro-molecule is the basis of manufacture of "Philite" materials. If we remember that the initial materials are fluid (or at least solids with low melting points) and the final product is a hard mass resembling ebonite in appearance, it is evident that in the course of the finishing process considerable changes must have taken place. In practice it may be observed that the transition to the solid finished product takes place very gradually. At first the phenol and formaldehyde form a resin-like viscous fluid, which on further heating gradually hardens to a consistency comparable to that of asphalt, finally being converted into a very hard and infusible end product. The essential factor here is the formation of an asphaltic intermediate product, for in this stage the mass can be readily liquified in heated matrices (150 °C.) under hydraulic pressure, the

The moulding process in the case of artificial resins is thus fundamentally different from that employed with metals, such as cast iron, which is molten and then poured into a cold mould in which it is allowed to cool. The raw material for "Philite" is introduced into a hot mould in which it hardens as a result of chemical reaction specifically promoted by the application of a high temperature.

To make this important characteristic still more clear, compare the moulding process employed with that which must be used for producing moulded articles from a substance, such as asphalt.

Asphalt can also be liquified by placing into a hot mould and applying a pressure, although there is here no chemical reaction which results in a hardening process taking place. Hence to remove the shaped asphaltic article from the mould, the latter must be cooled and again reheated before pressing of the succeeding article can commence. With artificial resin this is naturally unnecessary, thus considerably accelerating the process of manufacture. But, as in most cases this advantage is not obtained without overcoming certain difficulties, since to obtain a satisfactory shape very high pressures are required of the order of 300 kg/sq cm. The matrices thus have to sustain very high stresses

and for this reason are usually fairly expensive.

Fig. 3 shows the variations in certain properties of the artificial resin with time during the pressing process. It is seen that the tensile strength, as well as the stability to heat, increases considerably. This is readily accounted for by a further glance at the reaction product shown in fig. 2 and when it is remembered that the various chemical bonds in this molecule have a high energy value (100 to 200 kilo-cals per gr. equivalent). The significance of this is that a considerable amount of energy has to be absorbed either in the form of mechanical or thermal energy to split these bonds again, thus accounting for the mechanical and thermal stability.

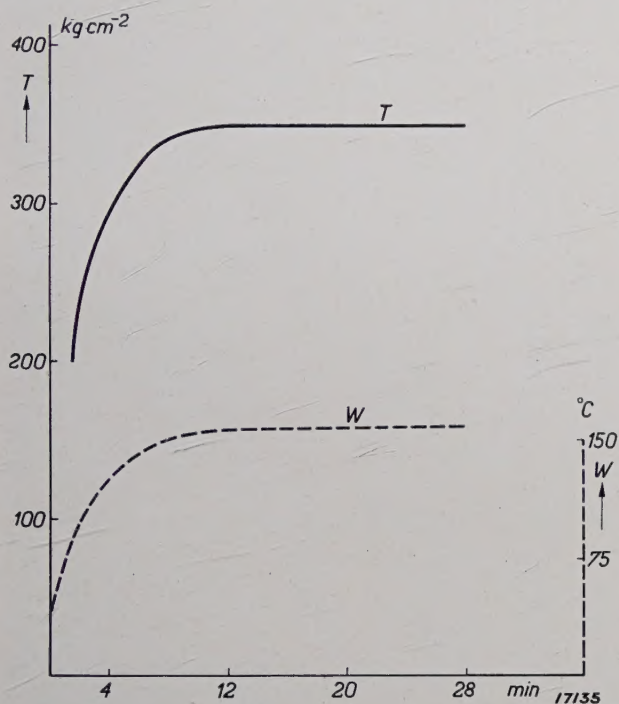


Fig. 3. Increase in the tensile strength T and the stability to heat W of an artificial resin with increasing duration of pressing.

In this brief survey we have limited ourselves merely to the artificial resin constituent and have made no mention of the fillers in "Philite", since a discussion of these latter does not enter into the scope of the present article. In this connection it may, however, be mentioned that these fillers have a marked effect on both the electrical and the mechanical properties of the finished material, such that by a rational combination of various types of artificial resins and different fillers a very varied range of products can be obtained. This is indeed one of the reasons why "Philite", as already indicated, can frequently be very easily adapted to meet specific requirements.

Comparison with other Insulating Materials

It has already been pointed out that "Philite" is able to satisfy simultaneously a number of different requirements and just for this reason it is frequently better than other insulating materials. To obtain a closer insight into this comparison the principal requirements generally determining the choice of an insulating material have been collated in Table I. This summary is, of course, not complete since in the first place a comparison is limited to merely some of the principal properties. Other properties entering into question will be indicated later, as well as the position of "Philite" in respect of these.

The most important property of interest in insulating materials, the disruptive strength, has in the case of *Philite S* the not too high value of approx. 8 kV per mm. For ordinary low-voltage applications this disruptive strength is however quite adequate, the difference as compared with the higher values given for the three other materials being of no special moment. In fact where for high-

Table I. Comparison of the Properties of Different Insulating Materials

	Tensile strength	Impact value	Stable up to temperatures of		Disruptive strength	Specific gravity	Tolerances	Ease of surface treatment
			Long periods	Short periods				
	in kg cm ⁻²	in kg cm ⁻²	°C	°C	in kV mm ⁻¹	gr/cm ³	%	
"Philite" moulding material (Type S)	350	7	140	160	8*	1.35	0.2	Good
"Philite" sheet material (Philitax)	750	30	140	150	25	1.35	—	Good
Porcelain	300	2	about 1000	about 1000	30	2.5	1	Bad
Cellulose derivatives (Philite A)	300	50	50	50	50	10	1.3—1.6	Very good
Ebonite	400	10	60	60	10		1.1—1.7	Very good

*) Other types of "Philite" have a higher disruptive strength, up to 30 kV/mm.

tension purposes, a greater value is desirable this can also be met as shown in Table II.

With the aid of Table I let us compare the other principal properties of other insulating materials with those of "Philite" S. Consider first the mechanical strength as expressed by the tensile strength and the impact value; it is seen that porcelain has a very low impact value of 2 kgcm per sqcm, the wellknown fragility of porcelain making it in fact quite unsuitable for many purposes. Again as regards stability to heat it is observed that just those bodies, such as cellulose derivatives and ebonite, which have quite satisfactory mechanical values, give low values for this property, mainly because the maximum temperature they can sustain is below 100 °C., a temperature level which is of very great importance in technology. In this respect porcelain naturally offers a quite unmistakable advantage, which organic bodies, such as the artificial resins, can perhaps never hope to equal. This range of high temperatures will, it appears, therefore remain the preserve of the inorganic substances; but the applications at which such a high temperature level is not required are so numerous that a very wide field still remains for the organic insulators. And just in these applications the various kinds of "Philite" can prove of inestimable value, since e.g. specific temperature requirements in the tropics can be very readily met, even if an extra although not excessive amount of heat is evolved in the electrical apparatus itself.

As regards the dimensional tolerances which can be obtained in the products, a factor frequently of paramount importance, it is well known that in mass production the choice of a material is often determined by the tolerances within which a moulded product can be made. This is another reason why very often porcelain is rejected in favour of "Philite" S with its fivefold smaller tolerance of approx. 1 per cent., particularly as porcelain, as indicated in the last column, is very difficult to work, so that any deviations in dimensions are difficult to correct.

On the whole the principal advantages of "Philite" over porcelain are its greater impact strength and its greater accuracy in workmanship. Other advantages are its low specific gravity, its pleasing appearance and the wide range of colours in which it can be made. "Philite" is of the same colour throughout and is not merely covered with a thin varnish which can be readily damaged.

For outdoor use and under conditions in which temperatures exceeding 150 °C. may occur, pro-

celain is naturally to be preferred to "Philite".

Comparing "Philite" S with cellulose derivatives and ebonite, the very low stability to heat of the two latter is the chief reason for serious objection being frequently raised against their use. It is thus seen that each of the insulating materials listed possesses at least one important property which does not compare with that of "Philite" S.

In addition to its suitability for making all standard moulded products, "Philite" can also be employed for making special compound products in which metal or other parts are pressed into the material. *Fig. 4* shows a radiograph of a moulding

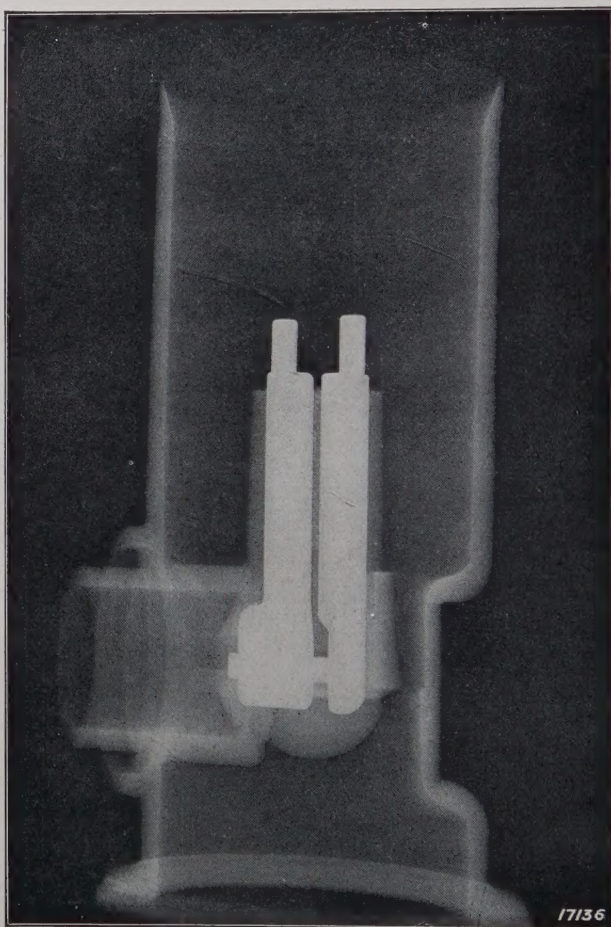


Fig. 4. Radiograph of a moulded product made of "Philite" into which metal parts have been pressed (shown white in the picture).

where the metal component has been completely embedded in the "Philite". *Fig. 5* shows diagrammatically how such a metal part, here a threaded nut *M*, is pressed into the "Philite". The nut is placed on the pin *P* of the opened matrix *O*, which is then filled with the powdered raw material (*Ph*) (*Fig. 5b*). During pressing the mass does not fill all the cavities in the matrix but also flows round the metal parts (*fig. 5c*). *Fig. 5d* shows how the

"Philite" (*Ph*) after hardening in the matrix has completely surrounded the brass nut *M*, holding it firmly. Here again it is possible to work to narrow tolerances, for the position of the brass nut is determined entirely by the pin *P*, which is attached

above, the latter being regarded as a standard of comparison.

It is evident that in view of the wide variety of demands which technology makes as regards an insulating material it is practically impossible

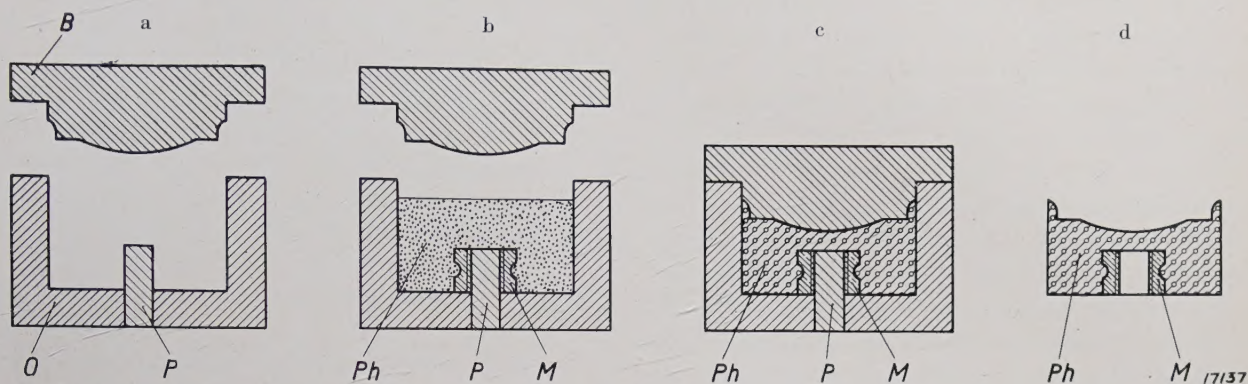


Fig. 5. Manufacturing process for pressing in a brass nut *M* into "Philite" *Ph* which is moulded by pressing in a lower matrix *O* and an upper matrix *B*.

- Matrix open.
- Inserting the brass nut *M* and filling with raw mixture.
- Closing the matrix.
- Finished product with embedded nut.

to a solid part *O* of the matrix. This method of embedding metal parts is much simpler than the process employed in which holes are first drilled in the moulded article and the metal part then secured by putty or screwed in.

Special Kinds of "Philite"

In the following, brief reference will be made to several varieties of "Philite", each of which differs in some particular or other from "Philite" S referred

to find a single substance which will satisfy every single requirement. For this reason a large range of special types of "Philite" have been evolved and are employed for various products. Table II gives a survey of a selection of these varieties and also includes, to facilitate comparison, the corresponding properties of the standard "Philite" S. For the other kinds of "Philite", figures are only given where the relevant properties differ appreciably from those of "Philite" S.

Table II. Some of the Principal Properties of Special "Philite" Products *)

	Tensile strength	Impact value	Stable up to temperatures of (long period)	Disruptive capacity	Tan δ in 10^{-4} at 200 m ($1.5 \cdot 10^6$ cycles)	Other characteristics
	in kg cm $^{-2}$	in kg cm cm $^{-2}$	in $^{\circ}$ C.	in kV mm $^{-1}$		
"Philite" S	350	7	140	8	500	See Table I. For high temperatures. High tension material for indoor situations. 20 000 per matrix and per week; not stable to heat. General high-frequency use.
"Philite" I	—	—	180	1 tot 5	—	
High-tension "Philite" . . .	—	—	—	30	—	
High-frequency "Philite" P	—	—	60	20	2 tot 5	High impact strength. Transparent. Inter alia, unattacked by strong HCl, 30 per cent sulphuric acid and HF.
High-frequency "Philite" 160 (in various kinds)	Between 200 and 300, according to kind	—	180	30	55	
Flaked "Philite"	—	10—15	—	about 1	—	
"Transphilite"	—	—	—	—	—	
Acidproof "Philite"	—	—	—	—	—	

*) For the sake of simplicity only those values are given for each material which differ considerably from the corresponding values for "Philite" S. On application the exact values for the properties of each specific material will be gladly supplied.

The first requirement specified by users of artificial resins is their ability to withstand high temperatures. It is obvious that in the case of an organic body, such as an artificial resin, the same high stability cannot be attained as with, for instance, porcelain. Nevertheless a satisfactory stability to prolonged heating up to 180 °C. can be attained as indicated for "Philite I" in Table II, and which is quite satisfactory for a large number of technical applications.

The very frequent demand for a material with a very high electrical disruptive value is met by *High-Tension Philite* which has a disruptive strength of 30 kV per mm, a value roughly the same as that for porcelain. Although the use of this material is limited to indoor locations, it yet offers many advantages over porcelain in view of its high mechanical stability and the low dimensional tolerances to which it can be worked, as well as the ease with which metal parts can be pressed into it, so much so that it has already found very extensive use.

Two types of high-frequency "Philite" have been evolved to meet the increased demand for materials with low dielectric losses. *High-frequency Philite P* with a value of $\tan \delta = 2$ to $5 \cdot 10^{-4}$ offers exceptional advantages in this respect, and enables values to be obtained which are nearly equal to the best other materials in this class, such as mica and quartz, but which are not susceptible to moulding. On the other hand, this material has the disadvantage that its stability to heating is low, viz., about 60 °C. To overcome this difficulty *High-Frequency Philite 160* was evolved which can be produced with different tensile values, and similarly to "Philite I" can withstand heating to a temperature of 180 °C. Although this advantage has been gained to a certain extent at the expense of the phase difference, yet $\tan \delta = 55 \cdot 10^{-4}$ as compared with "Philite S" ($\tan \delta = 500 \cdot 10^{-4}$) is so low that Philite 160 still has many practical applications.

The mechanical strength will naturally always remain an important consideration, especially as "Philite" has in recent years become extensively employed in directions other than those for which it was originally intended, viz., as an insulating material, and in these supplementary applications properties entirely foreign to good insulation have been required. The impact value of 10 to 15 kg-cm per sq cm of "*Flaked Philite*" closely approaches that of various kinds of wood, and components made of this material thus possess very high mechanical values. Whilst the insulation properties have become slightly reduced, the final product

is still an insulating material with exceptional impact strength.

"*Transphilite*" is a material which is made with a variety of transparent colours and is used for certain lighting fittings.

A special "Philite" product which must be mentioned is the *acid-proof variety of "Philite"* which has been evolved for use in chemical works, being practically unattacked by various concentrated acids. It is interesting to note that contrary to glass this product is not attacked by hydrofluoric acid, and in view of this property it is frequently employed in place of glass.

Flat sheets of "Philite"

Up to the present reference has been limited to artificial resins which could be moulded to any desirable shape. In addition there is a series of artificial resins which are only suitable for manufacturing flat sheets which can be easily cut with the saw. Sheet "Philite" is supplied in various kinds, distinguished for exceptional mechanical properties, in this respect being comparable to wood.

"Philitax", whose principal properties are enumerated in Table I, is one of the best materials for making insulating sheets. In small thicknesses (e.g. 1.5 mm) it can be easily cold stamped, as well as hot stamped up to a thickness of 7 mm. In this way simple mass-production articles can be produced from it as shown in *fig. 6*, and similar

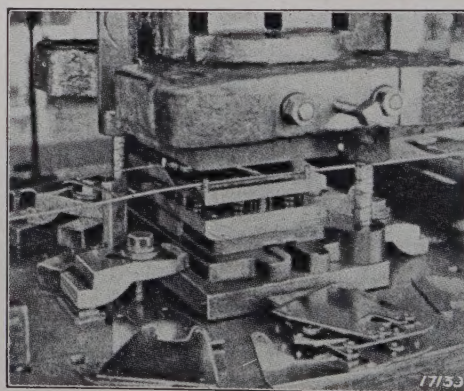


Fig. 6. Stamping of articles from "Philitax" sheet material.

to stamped metal plates and sheets. It is not only extensively used in the construction of switchboards, but also for interior components in a large range of electrical apparatus since owing to the ease with which it can be worked it combines cheapness with desirable mechanical and electrical properties, without requiring expensive matrices.

"Philitext" meets the need for a very high impact value, which in the case of this material is 50 kg cm cm⁻². Electrically, this material is not

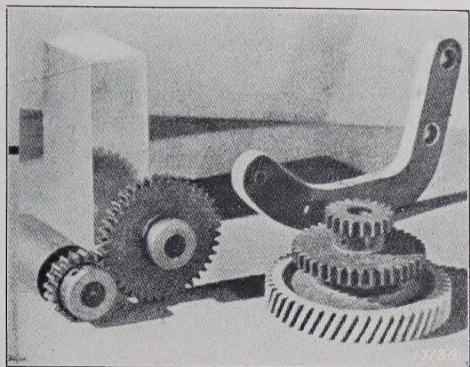


Fig. 7. Silent gears made of "Philitext".

quite comparable to "Philitax" whose electrical characteristics are high; it has become widely adopted since it is suitable for manufacturing bearings which can be water lubricated, as well

as for making silent gear wheels, a selection of which is illustrated in *fig. 7*. In these directions in particular "Philitext" offers a number of still further potentialities. It should be mentioned in this connection that the friction of bearing materials made with artificial resin as a base is roughly comparable to that of good bearing metals (coefficient of friction 0.1). In addition artificial resins have the advantage of being unattacked by acids and alkalies, permitting lubrication with water and offering a long life.

This brief outline of the characteristics and properties of the "Philite" range of artificial resins will suffice to indicate to what extent the varied requirements of consumers can be met. Technological advances, however, continue to be made and it may be confidently expected that in the course of the next few years further additions will be made to the comprehensive list of existing "Philite" products and which will in their turn meet other specific requirements.

IMPROVEMENTS IN RADIO RECEIVERS

By C. J. VAN LOON.

Summary. Two important improvements in radio receivers, viz., touch tuning and low-frequency counter-coupling, are discussed in detail.

In touch tuning sharp tuning is indicated by the turning of the tuning knob suddenly becoming stiffer; in the circuit employed a braking magnet which brakes the tuning-knob shaft is magnetised on sharp tuning. This device has been supplemented by an arrangement which by mechanical means keeps the set perfectly silent as long as no station has been sharply tuned in.

With low-frequency counter-coupling the distortion occurring in low-frequency amplification is reduced to a small fraction of its value in the absence of counter-coupling, the frequency relationship of amplification being favourably influenced at the same time.

Introduction

The most important characteristics of radio receivers are unquestionably their purity of reproduction, their selectivity and their sensitivity. In the course of the technical development of receiving sets the quality of reproduction has been improved in various directions, thus the acoustic reproduction of the loudspeaker, which during the first few years of broadcasting was limited to a comparatively narrow range of audio-frequencies, has steadily been improved upon such that a range of for instance 40 to 10 000 cycles/sec. can now be reproduced with satisfactory uniformity. Furthermore, the technical design and construction of the various amplifying stages in a receiver and the outputs of the amplifying and output valves have been raised to a high stage of development, these advances being naturally also to the marked advantage of purity of reproduction.

Controllable Band Width

Similar far-reaching improvements have also been achieved in regard to the selectivity of sets, such refinement having become indispensable under present-day conditions of broadcasting with powerful transmitters utilising frequencies which are extremely to those employed by weak stations. On the other hand, however, a very high selectivity cannot be coupled with the requisite purity of reproduction. A small resonance curve as shown in *fig. 1a* results in the side bands of the incoming signal being damped, so that high modulation frequencies are far too weak and reproduction sounds heavy or "flat". An improvement is obtained by making the resonance curve less sharp (see *fig. 1b*), when as large as possible a portion of the side bands is transmitted undamped. Further investigations in this direction have led to the so-called "controllable band width" which is used

to an increasing extent in superheterodyne receivers. By adjustment of the coupling between the circuits in the intermediate frequency section, the

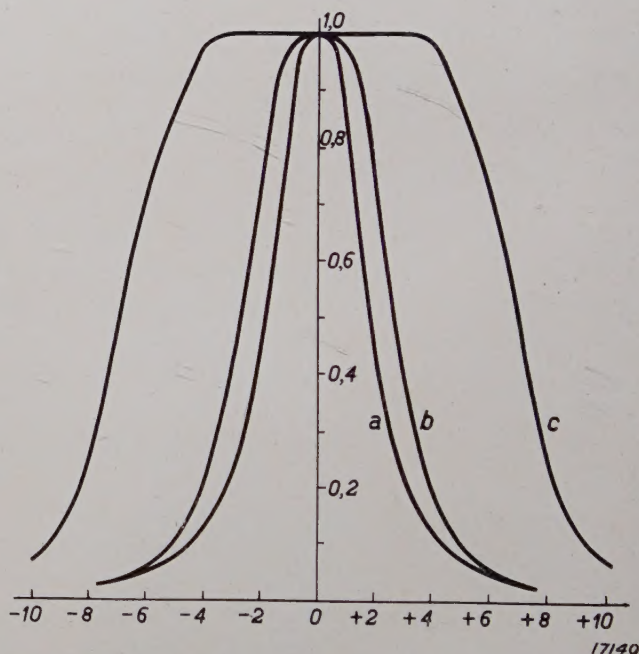


Fig. 1. Resonance curves, with intensity plotted as a function of the detuning in kilocycles.

- a) Small resonance curve; the higher modulation frequencies are reproduced much too weakly.
- b) Smoother resonance curve: a greater part of the side bands is transmitted undamped and the selectivity is lower.
- c) Example of a resonance curve as obtained with controllable band width on adjustment to "wide".

resonance curve can be made narrower (as shown in *fig. 1b*) or wider (as in *fig. 1c*) just as required. A wide transmission band is employed where a high selectivity is not required, since the transmitter tuned in is powerful or there is no interference from adjoining stations; the high audio-frequencies are then not weakened so that reproduction is of an exceptionally high quality. Where a high selectivity is required under the conditions ruling, a narrower transmission band is chosen, which

however unavoidably leads to a loss of the high notes.

Automatic Volume Control

An improvement which has been incorporated in a large number of radio-receiving sets for several years is the automatic control of volume, consisting in producing an automatic decrease in the amplification of a set as the signal at the detector becomes more powerful. The marked differences between the input signal voltages (a medium-strength signal, for instance, gives 0.1 millivolt in the aerial, and the signal from a powerful local station, 500 millivolts) are reduced considerably in the set itself by the automatic volume control.

The pronounced advantages of automatic volume control both as regards fluctuations in the strength of the station tuned in (fading effects) and when listening in to a number of stations of different outputs in succession, are too well known to require detailed discussion. Such control, however, introduces a number of difficulties; for instance it is more difficult with an A.V.C. to determine sharp tuning of a station. In receiving sets without automatic volume control sharp tuning presents no difficulty, for tuning by ear is merely continued until a maximum volume of reception is obtained. On the other hand, accurate, audio-tuning is much more difficult in those sets equipped with automatic volume control and also having a resonance curve with a flat peak; on slight detuning of the set there is no detectible difference in volume since automatic control compensates for any reduction.

It thus becomes necessary to employ as a criterion of correct tuning a maximum volume of the low notes or a minimum of distortion. This method of tuning requires, however, considerable skill with the result a set of this type is frequently flat tuned, thus affecting the purity of reproduction owing to the absence of the low notes and the occurrence of distortion.

"Touch" Tuning

It is not surprising, therefore, that means have sought to eliminate these difficulties and which would indicate in a simple manner when sharp tuning was realised. One method evolved for this purpose was that of "visual" tuning in which a maximum or minimum deflection of a pointer was obtained when tuning was sharp. Circuits were also evolved with which, as in early receiving sets, a fairly definite maximum volume was ob-

tained when sharp tuning was attained so that tuning was again an audible process. In this laboratory an entirely new method of tuning has however been developed, viz., a method of "touch" tuning, which considerably facilitates accurate adjustment. Sharp tuning is here indicated by a sudden braking of the tuning knob, being achieved by means of a circuit in which as sharp tuning is approached there is a sudden increase in current which is utilised to hold the tuning shaft by means of a magnet. An arrangement can also be quite easily incorporated with this circuit which by mechanical means keeps the receiver completely silent until it has been sharply tuned to the station (so-called "silent" tuning); as soon as the braking magnet is energised a contact is closed at the same time which connects up the loudspeaker system. In this way "touch" tuning is combined with "silent" tuning.

We shall discuss the operation of the "touch" tuning circuit with the aid of a number of diagrams. Assume that the receiving set which has to be equipped with the "touch" tuning system is a heterodyne receiver of the type shown diagrammatically in *fig. 2*.

When the set is sharply tuned the high-frequency portion is adjusted to the frequency of the incoming signal and at the same time the oscillator tuned to a frequency such that the differential frequency generated in the mixer valve is exactly equal to the intermediate frequency f_0 to which the intermediate-frequency portion is tuned. On a slight departure from the sharp-tuning position by giving the tuning knob a little turn, the oscillator becomes detuned. The differential frequency has thus been altered and no longer coincides with the intermediate frequency. The circuits in the high-frequency portion are also detuned, so that in consequence there is a slight change in the amplitude of the signal passed to the mixer valve. If detuning is not excessive, then owing to the operation of the automatic volume control it may be expected that to a first approximation a signal whose frequency varies while the amplitude remains substantially the same will be obtained at the output of the intermediate-frequency amplifier, i.e. at P ; on sharp tuning the frequency is exactly equal to the intermediate frequency f_0 .

The circuit shown in *fig. 3* is now connected to P through a small condenser C_1 . This arrangement consists of a circuit (LCr) which is tuned to the intermediate frequency f_0 . The oscillating alternating voltage in this circuit is rectified by the diode D , so that a direct voltage is obtained at

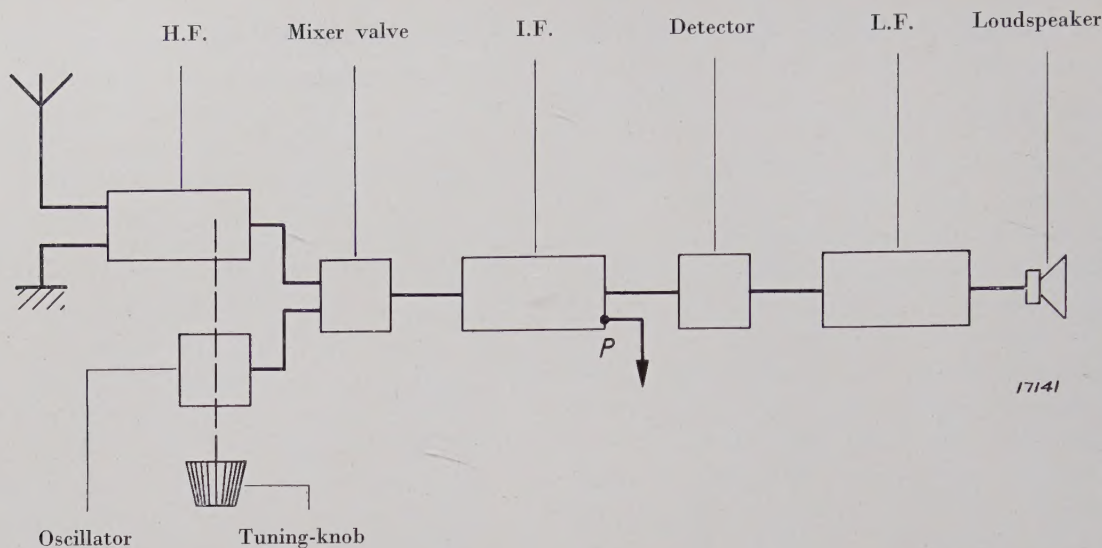


Fig. 2. Circuit of a super-heterodyne receiver. The intermediate-frequency signal for touch tuning is tapped from the point *P*.

the resistance *R*, which is by-passed by the condenser *C*₂. *R* is also connected in series with a direct-current source *V*_{*B*} whose negative pole

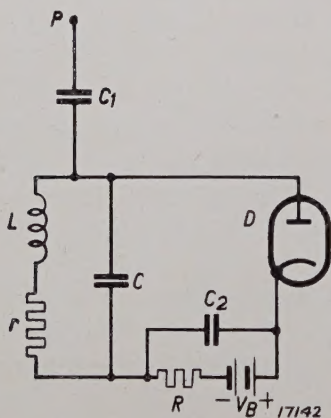


Fig. 3. Equivalent circuit for "touch" tuning. On sharp tuning of the set a voltage is obtained at *P* (see also fig. 2) which is passed through *C*₁ to the oscillating circuit *LCr* tuned to the intermediate frequency; on sharp tuning the voltage in this circuit is greater than *V*_{*B*} so that the diode *D* with which the threshold voltage *V*_{*B*} is connected in series acts as a rectifier and furnishes a direct voltage at the resistance *R* which serves for operating a braking arrangement. As detuning becomes greater the voltage in circuit *LCr* become smaller, so that from a certain degree of detuning *V*_{*B*} prevents rectification and the brake no longer operates.

is connected to the anode, so that in the absence of alternating voltage in the circuit the anode of the diode is negative with respect to the cathode. It should be noted that a rectified current only commences to flow when the amplitude of the alternating voltage is greater than the threshold voltage *V*_{*B*}.

When the receiver is sharply tuned pole *P*, as

we have seen, will have a voltage with the frequency *f*₀. The voltage resulting therefrom in the oscillating circuit will have an amplitude *V*₀. On slight detuning the amplitude of the voltage in *P* will remain practically unchanged. If the frequency is altered to *f*₀ + Δ*f* (or *f*₀ − Δ*f*) the circuit voltage will then drop to:

$$V_o \frac{1}{\sqrt{1 + \left(\frac{4\pi\Delta f}{r/L}\right)^2}}$$

If *V*₀ > *V*_{*B*} the diode will pass current at tuning and a direct voltage will be produced at *R*. On detuning this current ceases to flow as soon as Δ*f* reaches a limiting value Δ*f*_{*lim*} as expressed by the equation:

$$V_o \frac{1}{\sqrt{1 + \left(\frac{4\pi\Delta f_{lim}}{r/L}\right)^2}} = V_B \dots (1).$$

Thus by a suitable choice of the threshold voltage *V*_{*B*} it is possible to determine in what frequency range on both sides of the resonance frequency *f*₀ rectification will occur and a direct voltage be obtained at resistance *R*. This direct voltage can, for instance, be utilised for modulating an amplifying valve such that a magnet inserted in the anode circuit of this valve will brake the tuning-knob shaft.

By this method "touch" tuning of stations of a specific strength becomes possible. But if a station is chosen with e.g. a much greater strength, the voltage in *P*, in spite of automatic volume control, can be as much as several times greater than in the

case just considered. As a result the frequency sweep over which "touch" tuning is effective will also increase. Consider the example of a circuit in which $r/L = 6280 \text{ sec}^{-1}$ and $V_B/V_0 = 0.86$. From equation (1) we get $\Delta f_{lim} = 300 \text{ cycles/sec}$. If for a more powerful station V_0 is, say, twice as powerful, V_B/V_0 will be 0.43 and hence Δf_{lim} will be 1050 cycles/sec. The range over which touch tuning operates thus varies fairly considerably for transmitters of different strengths, so much that the tuning knob in the case of the powerful stations becomes already braked at an excessive distance from the sharp-tuning position.

This difficulty may be overcome in the following way. It follows from equation (1) that for a given value of r/L the term Δf_{lim} will also have a definite value, provided the ratio of V_B to V_0 is unchanged. This would be the case if in the circuit shown in fig. 3 the threshold voltage V_B were not constant but increased in proportion to V_0 . Fig. 4 shows how this is achieved and represents two circuits, I and II, which are both tuned to the intermediate frequency, as well as two rectifying diodes. C_3 is a small condenser.

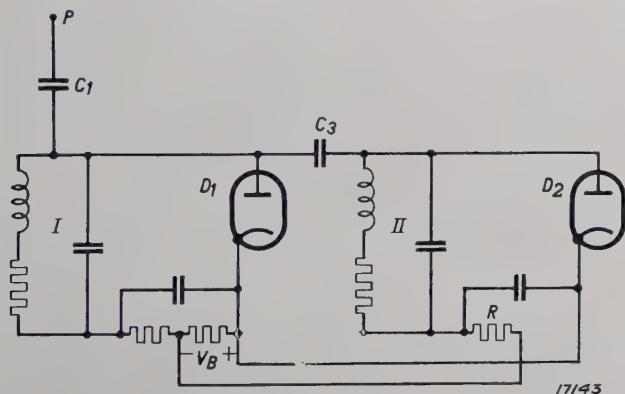


Fig. 4. Improvement of the circuit shown in fig. 3. The voltage of circuit I is rectified by the diode D_1 . A part of the direct voltage obtained serves as the threshold voltage V_B for the second rectifying circuit (circuit II, diode D_2 , resistance R). By means of this circuit the diode D_2 always rectifies in the same frequency range on both sides of the sharp tuning position, almost independently of the signal strength in P .

The diode D_1 rectifies the voltage in circuit I, part of the rectified voltage constituting the threshold voltage V_B for the rectifying circuit of D_2 . This circuit ensures that the rectifying action of the diode D_2 always commences at the same degree of detuning Δf_{lim} irrespective of the signal strength in P , whereby a direct voltage is obtained at the resistance R which through an amplifying valve energises the braking magnet.

In the practical design of this arrangement as shown in fig. 5 circuit I is not connected directly

to P in the intermediate-frequency section, but is linked up through an amplifying valve L . Valve L is modulated by the rectified voltage at R ; in the sharp tuning range the voltage at R makes the

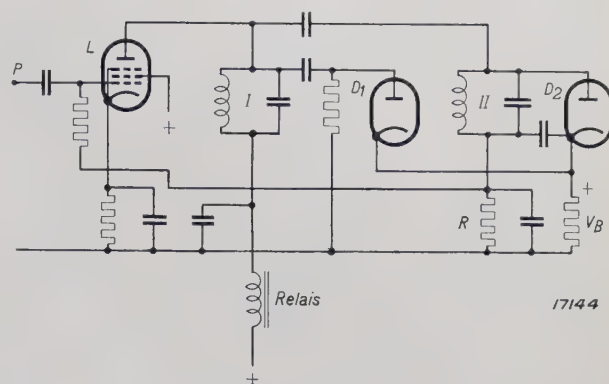


Fig. 5. Practical design of a circuit for touch tuning. Circuit I (cf. also fig. 4) is not connected directly to the intermediate frequency portion at P but through an amplifying valve L . The direct voltage obtained at R on sharp tuning is passed to the grid of L and reduces the anode current in this valve; as a result the relay trips and the brake comes into operation.

grid of L more negative so that the relay inserted in the anode circuit of L trips and thus closes a contact in a circuit which energises the braking magnet. If the relay simultaneously closes a second contact, for instance for switching on the loudspeaker, a "silent" tuning system is arrived at in a very simple way.

Fig. 6 gives a view of the braking system where an iron disc is attached to the tuning-knob shaft opposite to the braking magnet. This disc is secured on the shaft by a spring and cannot be turned about the shaft but only displaced along it, so that it is attracted towards the braking magnet when the latter is energised.

Counter-coupling

Brief reference has already been made above to the fact that developments in radio valves, and in particular in output valves, have also included an improved purity in reproduction. The immediate means for reducing the distortions in reproduction has appeared to be the introduction of high-output last-stage valves. At the same time a circuit was evolved in this laboratory, which has been employed in a variety of receiving sets and which may be termed that of low-frequency counter-coupling. With this circuit the distortion occurring in the low-frequency part of a receiver is reduced to a very small fraction of its initial value, while at the same time the frequency characteristics of reproduction are also favourably influenced.

If an alternating voltage V_g is applied to the grid

of an output valve, an amplified alternating voltage V_a will occur at the load resistance in the anode circuit. A part $n V_a$ of this output voltage

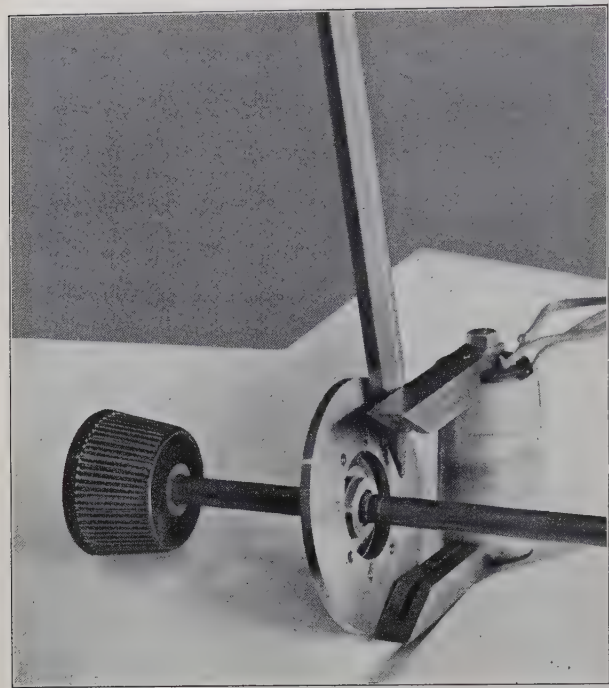


Fig. 6. Brake. An iron disc is fixed on the tuning-knob shaft opposite to the braking magnet. The disc is attached to the shaft by means of a specially-shaped spring and is therefore constrained to move along the shaft only, so that it is drawn towards the brake magnet when the latter is energised.

can be fed back to the input circuit. If this feedback voltage is in phase opposition to the input voltage V_i we can speak of counter-coupling (or opposed coupling). The amplification is reduced by this counter-coupling, as well as the distortion in almost the same ratio.

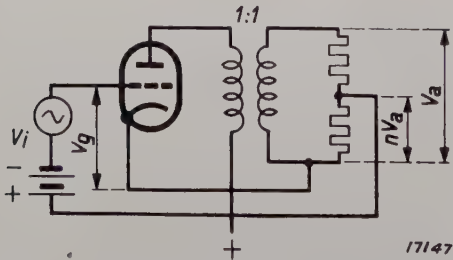


Fig. 7. Circuit of a counter-coupled output valve. A part $n V_a$ of the anode alternating current V_a , which is generated by the grid alternating current V_g , is fed back to the grid in phase opposition to the input voltage V_i .

The circuit of a counter-coupled output valve is shown in fig. 7; the load is not inserted directly in the anode circuit but is connected up through an ideal transformer with a 1:1 ratio in order to be independent of the direct voltage of the anode

battery. If the amplification of the valve is m , we have $V_a = m V_g$. As furthermore $V_g = V_i - n V_a$ we thus get $V_a = m V_i - m n V_a$, or:

$$V_a = \frac{m}{1 + m n} V_i,$$

so that the amplification has been reduced by a factor $(1 + m n)$ by counter-coupling. If n is made so great that $m n \gg 1$ then V_a will approach the value V_i/n . Thus as the counter-coupling increases the amplification becomes progressively more independent of m , i.e. of the characteristics of the valve, so that the distortion also becomes steadily smaller owing to the non-linearity of the valve characteristics.

For a closer investigation, express the non-linearity between V_a and V_g as follows:

$$V_a = \alpha V_g + \beta V_g^2 + \gamma V_g^3 + \dots \quad (2).$$

The alternating voltage V_g is equal to $V_{gm} \cos \omega t$, which substituted in equation (2) gives:

$$V_a = \alpha V_{gm} \cos \omega t + \beta V_{gm}^2 \cos^2 \omega t + \gamma V_{gm}^3 \cos^3 \omega t,$$

To a first approximation¹⁾ this expression may be written as follows:

$$V_a = \frac{1}{2} \beta V_{gm}^2 + \alpha V_{gm} \cos \omega t + \frac{1}{2} \beta V_{gm}^2 \cos 2 \omega t + \frac{1}{4} \gamma V_{gm}^3 \cos 3 \omega t.$$

We thus have terms containing 2ω and 3ω , i.e. distortions due to the second and third harmonics respectively.

If we denote the amplitudes of the first, second and third over-tones of V_a by V_{a1} , V_{a2} and V_{a3} , we then get:

$$V_{a1} = \alpha V_{gm}, \quad V_{a2} = \frac{1}{2} \beta V_{gm}^2 \text{ and } V_{a3} = \frac{1}{4} \gamma V_{gm}^3$$

With counter-coupling we get for the relationship between V_i and V_g :

$$V_g = V_i - n V_a \quad (3).$$

Equations (2) and (3) together express the relationship between V_a and V_i . Let us write V_a also as a power series of V_i ; to do this we must first "invert" equation (2), thus getting:

$$V_g = \frac{1}{\alpha} V_a - \frac{\beta}{\alpha^3} V_a^2 + \frac{2 \beta^2 - \alpha \gamma}{\alpha^5} V_a^3 + \dots$$

Substituting from equation (3) we find:

$$V_i = \left(\frac{1}{\alpha} + n \right) V_a - \frac{\beta}{\alpha^3} V_a^2 + \frac{2 \beta^2 - \alpha \gamma}{\alpha^5} V_a^3 + \dots$$

After "inversion" this equation becomes:

$$V_a = \frac{\alpha}{1 + \alpha n} V_i + \frac{\beta}{(1 + \alpha n)^3} V_i^2 + \frac{\gamma (1 + \alpha n) - 2 \beta^2 n}{(1 + \alpha n)^5} V_i^3 + \dots$$

which neglecting the small terms as usual may be written as follows:

$$V_a = \alpha \frac{V_i}{1 + \alpha n} + \frac{\beta}{1 + \alpha n} \left(\frac{V_i}{1 + \alpha n} \right)^2 + \frac{\gamma}{1 + \alpha n} \left(\frac{V_i}{1 + \alpha n} \right)^3.$$

We have thus obtained the non-linear relationship between V_a and V_i with counter-coupling.

In the same way as adopted above we get for the amplitudes of the first, second and third harmonics the following expressions:

¹⁾ We neglect $\frac{3}{4} \gamma V_{gm}^2$ against α

$$V_{a1} = \alpha \frac{V_{im}}{1 + a_n},$$

$$V_{a2} = \frac{1}{2} \frac{\beta}{1 + a_n} \left(\frac{V_{im}}{1 + a_n} \right)^2,$$

$$V_{a3} = \frac{1}{4} \frac{\gamma}{1 + a_n} \left(\frac{V_{im}}{1 + a_n} \right)^3.$$

We thus see that to obtain the same output voltage V_{a1} when introducing counter-coupling an input voltage $V_{im} = (1 + a_n) V_{gm}$ is required, so that the amplification is reduced $(1 + a_n)$ times; at the same time V_{a2} and V_{a3} are reduced in the same ratio.

This is shown graphically in *fig. 8* where for the AL 4 output valve with an anode load of 7000 ohms the distortion with and without counter-coupling is plotted as a function of the energy passed to the anode load; the factor $(1 + a_n)$, which denotes the degree of counter-coupling was here taken as approximately = 4.

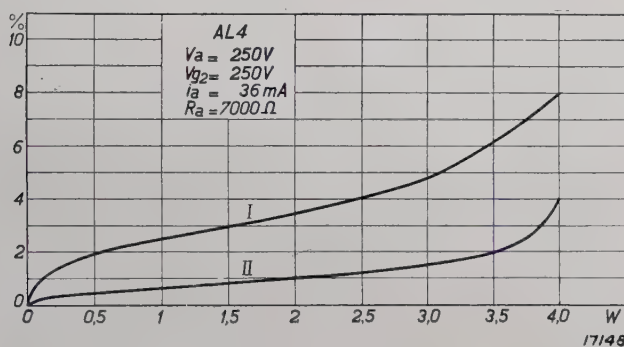


Fig. 8. Distortion in the AL 4 output valve with an anode resistance of 7000 ohms plotted as a function of the power developed in the anode resistance, without counter-coupling (curve I) and with fourfold counter-coupling (curve II).

In the above discussion we have in every case assumed an anode resistance independent of the frequency. Actually the load is provided by a loudspeaker whose impedance varies fairly considerably with the frequency. At the resonance point, which is usually situated between 50 and 100 cycles/sec. the impedance is a maximum.

Above this point it is practically constant over a specific range, increasing again at still higher frequencies. It is evident that this variation in impedance will affect the fluctuations in loudspeaker current or the loudspeaker voltage as the frequency varies and hence also the purity of reproduction. Counter-coupling thus offers a means whereby an arbitrary choice of the frequency characteristic can be made. If for instance for all frequencies the same fraction of the voltage V_a at the load is taken as the counter-coupled voltage, which will correspond to a fixed fraction n , the voltage V_a will vary progressively less with the frequency as the counter-coupling increases; eventually $V_a = V_i/n$, i.e. quite independent of the frequency. If, on the other hand, more powerful reproduction is desirable over a specific frequency range, for instance in the higher notes, the counter-coupling can be so adjusted that it is smaller for the range in question than for other frequencies.

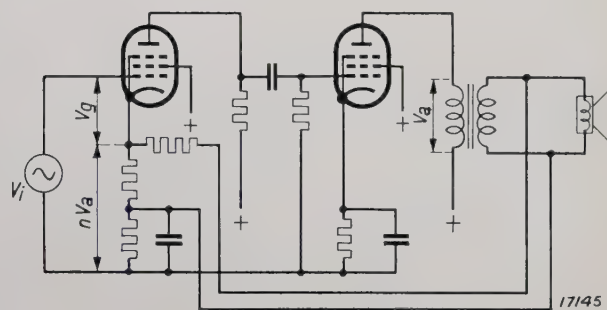


Fig. 9. Circuit for a counter-coupled amplifier in which the voltage is not fed back to the grid circuit of the output valve but to the grid circuit of the preceding amplifying valve.

Fig. 9 shows a further circuit in which the counter-coupling is not applied to the grid circuit of the output valve but to the grid circuit of the preceding amplifying valve. This offers, *inter alia*, the advantage that not only is the distortion in the output valve reduced but also the distortion in the whole of the two-stage low-frequency amplifier.

ELECTRICAL FILTERS II

Vacation course, held at Delft, April 1936.

By BALTH. v. d. POL and TH. J. WEIJERS.

PRACTICAL CALCULATION OF FILTERS WITH SINUSOIDAL E.M.F.

Summary. In this article the characteristics of filter sections are systematically discussed by the method of Campbell and Zobel¹⁾, in which the filters are defined by their image impedances Z_a and Z_b and the propagation constant T . Some simple fundamental types (T -sections, Π -sections and half-sections) are analysed in detail. From the characteristics of the filter sections the characteristics of compound filters can be directly derived, the filter sections of the latter being closed by their image impedances. Particularly useful for obtaining a systematic survey of the subject is a study of filters composed of non-dissipative impedances (inductances and capacities). In these cases there are sharply-defined transmission and attenuation bands in the frequency range. In the sections dealing with the m_T -transformation and the m_π -transformation, a method is outlined for deriving from T -or Π -sections a series of new filters having the same image impedances and transmission and attenuation bands, but a different propagation constant, the latter being defined by equations (25) and (31). If this transformation is applied to the asymmetrical half-sections only one of the image impedances remains unchanged, the other being altered as determined by equations (24) and (30).

Magnitudes, defining the filters

As indicated in the first article²⁾ the characteristics of a filter can be expressed in terms of three parameters. In the following¹⁾ we shall select for these three parameters the primary image impedance Z_a , the secondary image impedance Z_b and the propagation constant T . The calculation of these magnitudes for a given filter is based on another system of variables whose values can be readily determined, viz., the primary and secondary open-circuit and short-circuit impedances Z_{ao} , Z_{ak} , Z_{bo} and Z_{bk} , which being impedances of simple networks can be easily calculated. After determining these magnitudes we can calculate from them Z_a , Z_b and T using the formulae in the table on pp. 242 and 243 of the previous issue of this Review:

$$Z_a = \sqrt{Z_{ao} Z_{ak}}; \dots \dots (1)$$

$$Z_b = \sqrt{Z_{bo} Z_{bk}}; \dots \dots (2)$$

$$\tanh T = \sqrt{\frac{Z_k}{Z_o}} \dots \dots (3)$$

As $Z_{ak}/Z_{ao} = Z_{bk}/Z_{bo}$, in equation (3) this quantity has been abbreviated for the sake of simplicity to Z_k/Z_o . Equation (3) can also be written in the following form:

$$e^{-2T} = \frac{1 - \sqrt{\frac{Z_k}{Z_o}}}{1 + \sqrt{\frac{Z_k}{Z_o}}} \dots \dots (4)$$

In general Z_k and Z_o , and hence also T , are complex. If we put:

$$T = \alpha + j\beta$$

we get:

$$\frac{I_2}{I_1} = \sqrt{\frac{Z_a}{Z_b}} \cdot e^{-T} = \sqrt{\frac{Z_a}{Z_b}} \cdot e^{-\alpha - j\beta} \dots \dots (5)$$

It is thus seen that α determines the attenuation and β the phase difference between I_1 and I_2 .

Filter sections

The design of a filter to meet specific requirements usually consists of a stepwise process of compounding a certain number of filter sections. We shall limit discussion below to the symmetrical T -section, the symmetrical Π -section and the half-section. As already indicated two impedances are all that are required for a symmetrical filter to define the characteristics of the filter. To construct a filter section we therefore start from two impedances Z_1 and Z_2 (fig. 1a) which are termed "full branches" and from these build up the sections enumerated in the manner shown in fig. 1b, c, d and e. If two half-sections are suitably connected in series, we get a symmetrical T -section or a symmetrical Π -section (fig. 2). A half-section can therefore be regarded as half a T -section or as half a Π -section.

¹⁾ Campbell, Bell Syst. techn. J., vol. 1, No. 2, 1922.
Zobel, Bell Syst. techn. J., vol. 2, No. 1, 1923.

²⁾ Cf. Philips techn. Rev., 1, 240, 1936. For the following see the large table line 3, column 3.

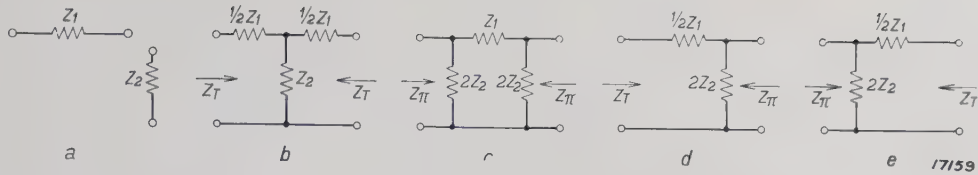


Fig. 1. Filter sections made up of the "full branches" Z_1 and Z_2 ,
 a) Full branches,
 b) Symmetrical T -section,
 c) Symmetrical H -section,
 d) Half-section,
 e) Half-section.

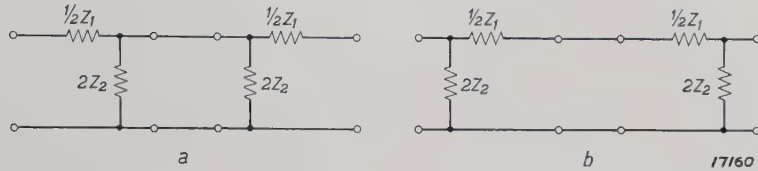


Fig. 2. a) T -section composed of two half-sections,
 b) H -section composed of two half-sections.

Compound Filters

A compound filter is obtained by connecting individual filter sections in series. The image impedance and the propagation constant of this compound filter may be determined from the corresponding value of the separate sections.

As already pointed out the primary image impedance Z_a is the impedance across the primary terminals 1 and 2 when the secondary terminals 3 and 4 are closed with the secondary image impedance Z_b (fig. 3).

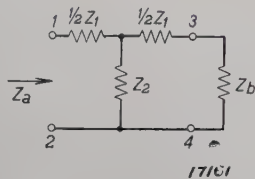


Fig. 3. Filter section, secondary closed with the corresponding image impedance.

It is immaterial how the impedance Z_b is produced; it can, for instance, even consist of a filter with a primary image impedance Z_b , whose secondary is closed by its own secondary image impedance Z_c . In the diagram (fig. 4) this second filter is equal to the

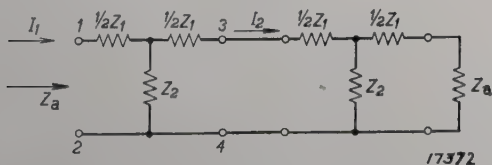


Fig. 4. Filter section, secondary closed with a closed filter section.

given filter, so that $Z_a = Z_b = Z_c$; this is naturally not imperative, for the only condition which must be met is that the interconnected image impedances must be equal and the output of the second filter must be terminated with the corresponding image impedance.

In this way filter chains can be compounded of any number of sections, the primary image impedance Z_a of the whole filter remaining equal to the primary image impedance of the first section. Hence the secondary image impedance of the whole filter is equal to the secondary image impedance of the last section. If the image impedance of the sections are different, the image impedance of the compound filter will not be equal to that of the terminal sections and will in general be an irregular, fluctuating function of the frequency. This gives the undesirable result that I_2/I_1 also will vary irregularly with the frequency. Thus in the practical design of filters it is usually to make the two image impedances at the junctions of two sections equal to each other. This is assumed to be so in every case in the following analysis.

The propagation constant T of the compound filter is calculated from the propagation constants $T_1, T_2, T_3 \dots T_n$ of the individual sections. We have seen above (5) that $I_2/I_1 = \sqrt{Z_a/Z_b} \cdot e^{-T}$. It follows from fig. 4 that the secondary current I_2 of the first section is the primary current of the second section. Similarly the secondary current I_3 of the second section is equal to the primary current of the third section, and so on. For a compound filter made of n sections we have therefore:

$$\frac{I_2}{I_1} = \sqrt{\frac{Z_a}{Z_b}} e^{-T_1};$$

$$\frac{I_3}{I_2} = \sqrt{\frac{Z_b}{Z_c}} e^{-T_2};$$

$$\vdots$$

$$\frac{I_{n+1}}{I_n} = \sqrt{\frac{Z_n}{Z_{n+1}}} e^{-T_n}.$$

The continued product of these equations is:

$$\frac{I_{n+1}}{I_1} = \sqrt{\frac{Z_a}{Z_{n+1}}} e^{-(T_1 + T_2 + \dots + T_n)} \quad (6)$$

The propagation constant of the compound filter is hence equal to the sum of the propagation constants of the individual sections.

The relationship between the primary and the secondary currents of the filter is deduced from the assumption that on the secondary side the filter is closed with its image impedance. In practice this is however never the case at all frequencies, so that I_2/I_1 is found to be a non-uniform function of the frequency in the transmitting bands; the deviations from uniform variation will be the greater the greater the secondary terminating resistance deviates from the secondary image impedance. An endeavour must therefore be made to match these two impedances as closely as possible in the transmission bands. As we have already seen, the image impedances of compound filter sections are equal to those of the terminal sections. In the following chapter it will be shown that the image impedance in the transmission band is a pure real resistance, which however varies with the frequency. We shall later discuss several special forms of terminal sections, in which the image impedance throughout the greater part of the transmission band is practically independent of the frequency. If a terminal section of this character is closed by a suitable constant resistance, a very close approximation to the above ideal case is obtained. The very tedious, accurate calculation of I_2/I_1 will not be dealt with in this series of lectures.

We shall study a large number of different classes of filter sections of which a few will have the same image impedances but different propagation constants which vary with the frequency. Filter sections will also be included with propagation constants of the same function of the frequency but with different image impedances. To construct a filter with a propagation constant meeting specific requirements, a number of known types of filter sections are linked up, their choice being such

that the sum of the propagation constants of the individual sections gives the requisite frequency function. Furthermore from the sections with the same propagation constant those types are selected that give the same image impedances at all junctions of the sections.

Filters composed of non-dissipative reactances.

Optimum energy conditions are required in the transmission band. If the filter contains resistances energy will be lost so that as a rule a filter will be built up from reactances self-inductances, capacities and mutual inductances having the minimum possible dissipation. True non-dissipative reactances cannot be realised, but the loss can be reduced to a minimum. We shall therefore first consider some characteristics of ideal filters composed of non dissipative reactances.

For these filters the open-circuit and short-circuit impedances Z_{ao} , Z_{ak} , Z_{bo} and Z_{bk} are imaginary (for certain specific frequencies zero or infinite), as they are impedances of networks composed exclusively of imaginary impedances. Z_k/Z_o as a quotient of two imaginary quantities is however real.

If in a certain frequency band Z_k/Z_o is negative then it follows from equations (1) to (5) that Z_a and Z_b are real and T is imaginary, i.e. $\alpha = 0$. A real impedance in a passive network is never negative, so that Z_a and Z_b are here positive and real. It thus follows from (5) that:

$$\frac{I_2}{I_1} = \sqrt{\frac{Z_a}{Z_b}}$$

Hence $|I_2|^2 Z_b = |I_1|^2 Z_a$, i.e. the apparent power input on the primary side of the filter is also available at the secondary. The filter thus causes no attenuation; this frequency band is thus a transmission band. The propagation constant is here $T = j\beta$ signifying that the phase angle between I_1 and I_2 is β . If in a particular case $Z_a = Z_b$ then $I_1^2 = I_2^2$; the amplitudes of the primary and secondary currents are then equal.

If in a particular frequency band Z_k/Z_o is positive, then we have *pari passu* that Z_a and Z_b are imaginary and $T = \alpha + j\beta = \text{complex}$, where $\alpha > 0$ and β is a multiple of $\pi/2$. We then have $I_2^2 Z_b < I_1^2 Z_a$; the apparent power output on the secondary side of the filter is thus smaller than the input of the primary side. The filter thus has an attenuating effect, so that this frequency band is therefore an attenuating band.

It is found from the above that for a filter

composed of non-dissipative reactances the image impedances in the transmitting bands are real and in the attenuating bands imaginary; they are therefore never complex.

The frequency at which a transmission band passes over into an attenuating band is termed the limiting frequency; Z_k/Z_o here changes from a negative to a positive value and is therefore zero or infinite.

Special importance attaches to the frequencies at which $Z_k/Z_o = +1$. For from equation (4) it follows that for these frequencies $e^{-2T} = 0$, so that from equation (5) $I_2 = 0$, i.e. the filter allows no current to pass with these frequencies, which are termed frequencies with infinite attenuation. It is also evident that the attenuation is infinite at $Z_k/Z_o = +1$, i.e. when $Z_k = Z_o$. $Z_{ak} = Z_{ao}$ signifies that shorting or opening the secondary terminals does not affect the impedance between the primary terminals and hence does not alter the current distribution in the filter. With the secondary terminals open just as little voltage is present as when these terminals are shorted. If an external impedance is connected across these terminals, no current will pass through it. But zero secondary current signifies an infinite attenuation.

These considerations naturally apply only approximately to non-ideal filters in which the coils and condensers always have a finite resistance. The transmitting and attenuating bands, the limiting frequencies and the frequencies with infinite attenuation are then defined as above, at the same time neglecting the resistances. In the transmitting bands there is a certain attenuation present; for "frequencies with infinite attenuation" the attenuation is then not infinite but has a maximum. In determining the image impedances the resistances in the filter coils and condensers can as a rule be neglected without introducing any error.

Image Impedances and Propagation Constants of Filter Sections after fig. 1.

The following three parameters are taken as defining a filter: the image impedances Z_a and Z_b and the propagation constant T . The filter sections in fig. 1 are however determined by the impedances Z_1 and Z_2 . We shall express the open-circuit and short-circuit impedances in terms of Z_1 and Z_2 and then with the aid of equations (1) to (4) obtain the image impedances Z_a and Z_b and the propagation constant T .

If we form a T -section from two half-sections (fig. 2a) then at the junction of the half-sections the condition is satisfied that equal image

impedances close each other: each of the two half-sections is the image of the other. If a Π -section is constituted from two half-sections (fig. 2b) this condition is similarly met. It thus follows that the image impedances of the T -section are the same as the image impedances of the half-section on the left of fig. 1d and that the image impedances of the Π -section are the same as the image impedances of the half-section on the right hand side of fig. 1d. Thus in fig. 1b to e there are only two different image impedances, which for the sake of clarity we shall no longer refer to as Z_a and Z_b but as Z_T and Z_π , as indicated in fig. 1. The image impedances and the propagation constant are most easily calculated for the half-section from the open-circuit and short-circuit impedances Z_o and Z_k . For the left-hand side of the half-section after fig. 1d we have:

$Z_o = \frac{1}{2} Z_1 + 2 Z_2; \dots\dots\dots (7)$

$Z_k = \frac{1}{2} Z_1 \qquad ; \dots\dots\dots (8)$

$Z_T = \sqrt{Z_o Z_k} = \sqrt{Z_1 Z_2} \sqrt{1 + \frac{Z_1}{4 Z_2}} ; \dots (9)$

For the right hand side of the half-section according to fig. 1d (left hand side of fig. 1e) we have:

$Z_o = 2 Z_2; \dots\dots\dots (10)$

$Z_k = \frac{2 Z_1 Z_2}{Z_1 + 4 Z_2}; \dots\dots\dots (11)$

$Z_\pi = \sqrt{Z_o Z_k} = \frac{\sqrt{Z_1 Z_2}}{\sqrt{1 + \frac{Z_1}{4 Z_2}}} \dots\dots (12)$

For both sides of the half-section we therefore get:

$\frac{Z_k}{Z_o} = \frac{1}{1 + \frac{4 Z_2}{Z_1}} \dots\dots\dots (13)$

The propagation constant T of the half-section then satisfies the equation:

$e^{-2T} = \frac{\sqrt{1 + \frac{Z_1}{4 Z_2}} - \sqrt{\frac{Z_1}{4 Z_2}}}{\sqrt{1 + \frac{Z_1}{4 Z_2}} + \sqrt{\frac{Z_1}{4 Z_2}}} ; \dots (14)$

which is obtained by substituting equation (13) in equation (4).

For a whole section, which whether of the T -or the Π -type may be regarded as a series combination of two half-sections, the propagation constant from equation (6) is double as great as for the half-section: thus for both the T -section and the Π -section we have:

$$e^{-T} = \frac{\sqrt{1 + \frac{Z_1}{4Z_2}} - \sqrt{\frac{Z_1}{4Z_2}}}{\sqrt{1 + \frac{Z_1}{4Z_2}} + \sqrt{\frac{Z_1}{4Z_2}}}; \quad \dots \quad (15)$$

We thus see that the magnitudes which define our filter sections³⁾ viz., Z_T , Z_π and T can be expressed in terms of $Z_1 Z_2$ and $Z_1/4 Z_2$. Since T depends merely on $Z_1/4 Z_2$, we will not calculate T but only $Z_1/4 Z_2$ and read T from a graph giving its value as a function of $Z_1/4 Z_2$. The method of graphical representation will be discussed in the next article.

As shown at the outset, in the case of filters composed of non-dissipative reactances Z_k/Z_o is negative and real in the transmission band. Expressed in terms of Z_1 and Z_2 this condition may be written according to equation (13) as follows:

$$-1 < \frac{Z_1}{4Z_2} < 0 \quad \dots \quad (16)$$

It follows herefrom that for the limiting frequencies one of the two relationships:

$$\frac{Z_1}{4Z_2} = \begin{cases} 0 \\ -1 \end{cases} \quad \dots \quad (17)$$

is satisfied. $Z_1/4 Z_2 = 0$, when $Z_1 = 0$ and $Z_2 \neq 0$, or when $Z_1 \neq \infty$ and $Z_2 = \infty$; $Z_1/4 Z_2 = -1$, when $Z_1 = -4 Z_2$.

For frequencies with infinite attenuation the condition applies: $Z_k/Z_o = +1$, from which through equation (13) we get:

$$\frac{Z_1}{4Z_2} = \infty \quad \dots \quad (18)$$

i.e. $Z_1 = \infty$ and $Z_2 \neq \infty$, or $Z_1 \neq 0$, $Z_2 = 0$. This may in fact be directly inferred, for if $Z_1 = \infty$, the branch will allow no current to pass and the secondary current is therefore zero; if $Z_2 = 0$, the voltage between the two ends of the branch will be zero and behind this branch, i.e. also between the secondary terminals, no current will flow. The cases where Z_1 and Z_2 are both zero or infinite require closer analysis.

m-Transformations

In the T - and Π -sections as shown in *fig. 1b* and *c* we have studied sections which have the same propagation constant but different image impedances. We shall now analyse a method by which

³⁾ There is a duality between T -sections and Π -sections. If in Π -sections the admittance $1/Z$ is introduced as a variable in place of the impedances Z , formulae are obtained for equations (10) to (12) which are almost identical with equations (7) to (9) for T -sections. In this way it is possible to apply the results of calculation for T -sections to Π -sections and vice versa. Equations (21) to (25) for the " m_T -transformation" and equations (27) to (31) for the " m_π -transformation" are examples of this.

from a given filter section which may be regarded as the fundamental type and whose characteristics are denoted by an accent, other sections can be derived which have the same image impedance, but different propagation constants. It has been shown above (p. 272) that the image impedances in the transmitting band are real and in the attenuating band imaginary. It follows from the fact that the derived filters have the same image impedances as the fundamental filter that both types also have the same transmitting and attenuating bands.

a) m_T -Transformation. We shall first analyse how from the half-section in *fig. 1d* another half-section can be derived, which on the left has the same image impedance $Z_T = Z_T'$. If in the expression $Z_T = \sqrt{Z_o Z_k}$ we multiply the short-circuit impedance Z_k with a positive real number m and divide the open-circuit impedance Z_o by the same value m , Z_T will remain unchanged. For the original half section $Z_k' = 1/2 Z_1'$, and for the transformed section we therefore have:

$$Z_k = 1/2 m Z_1'; \quad \dots \quad (19)$$

thus for the original section $Z_o' = 1/2 Z_1' + 2 Z_2'$ and for the transformed section:

$$Z_o = \frac{Z_1'}{2m} + \frac{2 Z_2'}{m} \quad \dots \quad (20)$$

The question now arises as to the composition of the filter section conforming with this conditions. If Z_1 and Z_2 are the impedances of the full branches of the transformed section, then it follows from equations (7), (8), (19) and (20), that:

$$Z_1 = m Z_1'; \quad \dots \quad (21)$$

$$Z_2 = \frac{1 - m^2}{4m} Z_1' + \frac{1}{m} Z_2' \quad \dots \quad (22)$$

With these values for Z_1 and Z_2 for a full section, a T -section, a Π -section and a half-section can be formed (*fig. 5*).

As the image impedance Z_T of the T -section (*fig. 5b*) is the same as the primary image impedance Z_T of the half-section (*fig. 5d*), the image impedances Z_T of the T -section (*fig. 5b*) and Z_T' of the fundamental type (*fig. 1b*) are equal, so that we have:

$$Z_T = Z_T', \quad \dots \quad (23)$$

independent of the choice of the parameter m . From equations (12) and (14) we get however that in the transformed half-section Z_π and T differ from Z_π' and T' . For these sections we then get from equations (12), (19), (20), (21) and (22) on putting $1 - m^2 = 1/a^2$:

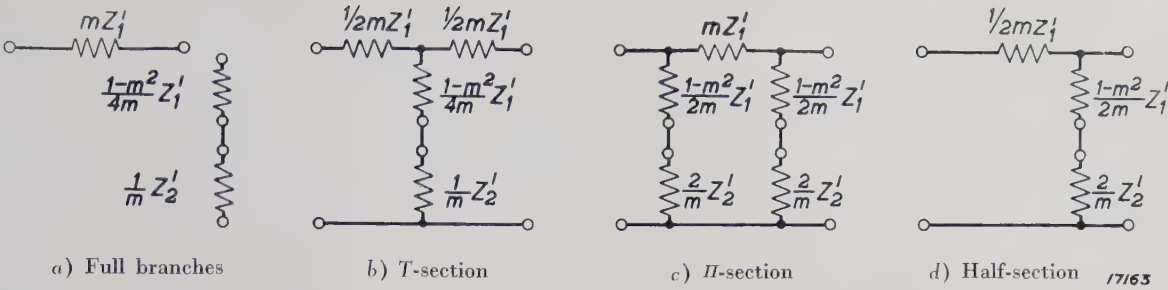


Fig. 5. m_T -Transformation. The image impedances Z_T of the T -section (b) are equal to the primary image impedance Z_T of the half-section (d, left) and are also equal to the image impedance $Z_{T'}$ of the fundamental type (fig. 1b). The image impedances Z_π of the Π -section (c) are equal to the secondary image impedance Z_π of the half-section (d, right), which is however not equal to the image impedance $Z_{\pi'}$ of the fundamental type (fig. 1c). The propagation constant T of the T -section (b) and the Π -section (c) are equal but not equal to the propagation constant T' of the fundamental types (figs. 1b and c).

$$Z_\pi = Z_{\pi'} \left(1 + \frac{1}{a^2} \frac{Z_1'}{4 Z_2'} \right); \dots \quad (24)$$

$$\frac{Z_1}{4 Z_2} = \frac{Z_1'}{4 Z_2'} \frac{m^2}{1 + \frac{1}{a^2} \frac{Z_1'}{4 Z_2'}} \dots \quad (25)$$

If therefore T -sections of the fundamental type and the transformed type are connected in series, equal image impedances will always be obtained at the junctions. This does not however apply to Π -sections.

It follows from equation (22) that an m_T -transformation is only rational when:

$$0 \leq m \leq 1 \dots \dots \quad (26)$$

If $m = 0$ the filter disappears; for $m = 1$ we arrive back at the fundamental type.

Since by this transformation of the fundamental type Z_T does not change, this method is termed that of m_T -transformation.

defined as those in which Z_π remains constant. A method analogous to that employed in the m_T -transformation can also be used in the m_π -transformation:

Z_1 = the parallel combination of $m Z_1'$ and $\frac{4 m}{1 - m^2} Z_2'$; (27)

$Z_2 = \frac{1}{m} Z_2'$; (28)

$Z_\pi = Z_{\pi}'$; (29)

$Z_T = Z_T' \frac{1}{1 + \frac{1}{a^2} \frac{Z_1'}{4 Z_2'}}$; (30)

$\frac{Z_1}{4 Z_2} = \frac{Z_1'}{4 Z_2'} \frac{m^2}{1 + \frac{1}{a^2} \frac{Z_1'}{4 Z_2'}}$ (31)

Here again condition (26) must be satisfied. It is seen from equations (25) and (31) that at the same

b) m_π -transformation. m_π -transformations are

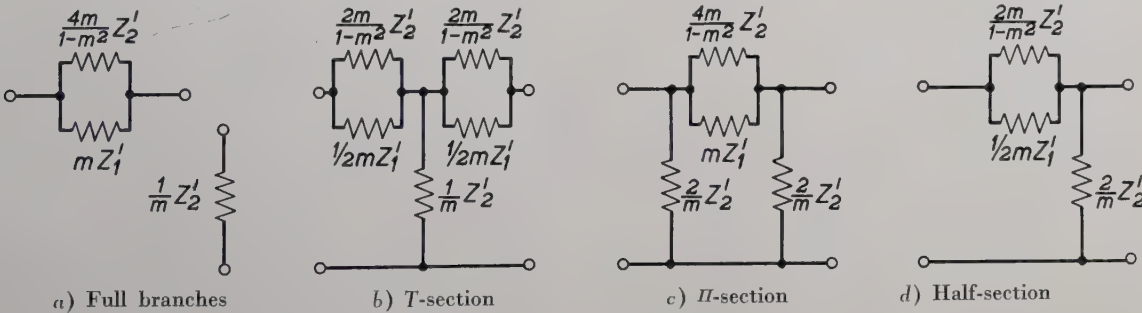


Fig. 6. m_π -Transformation. The image impedances Z_π of the Π -section (c) are equal to the secondary image impedance Z_π of the half-section (d, right) and also equal to the image impedance $Z_{\pi'}$ of the fundamental type (fig. 1c). The image impedances Z_T of the T -section (b) are equal to the primary image impedance Z_T of the half-section (d, left), but are not equal to the image impedance $Z_{T'}$ of the fundamental type (fig. 1b). The propagation constants T of the T -section (b) and of the Π -section (c) are equal to each other, and are also equal to the propagation constant for T - and Π -sections in m_T -transformation (fig. 5, b and c), but are to the propagation constant T' of the fundamental types (figs 1b and c).

value of m , $Z_1/4 Z_2$ and hence the propagation constant T is the same for both transformations. Fig. 6 shows how from these transformed branches of a T -section, a Π -section and a half-section can be produced. If Π -sections of the fundamental and transformed types are connected in series, the same

image impedances will always be obtained at the junctions. This does not however apply to T -sections.

It is evident that, for instance, after applying the m_T -transformation the transformed section can again be regarded as a new fundamental type and an m_π -transformation applied to it and vice versa.

Reactance Diagrams.

A general characteristic of networks composed of non-resistive reactances is a monotonic increase in the impedance with rising frequency, apart from discontinuous transitions from $+j \infty$ to $-j \infty$. As an example fig. 7 gives the reactances, which will be used later as filter branches, the reactance being plotted as a function of the frequency. In the case of reactances having more than two elements, several equivalent circuits can be obtained (figs. 7e to h).

These reactance diagrams offer a simple means for deriving at least qualitatively, the most important characteristics of the propagation constant of a specific filter section.

In the next article it will be shown how these reactance diagrams are utilised in the analysis of the various simple types of sections for low-pass, high-pass and band-pass filters.

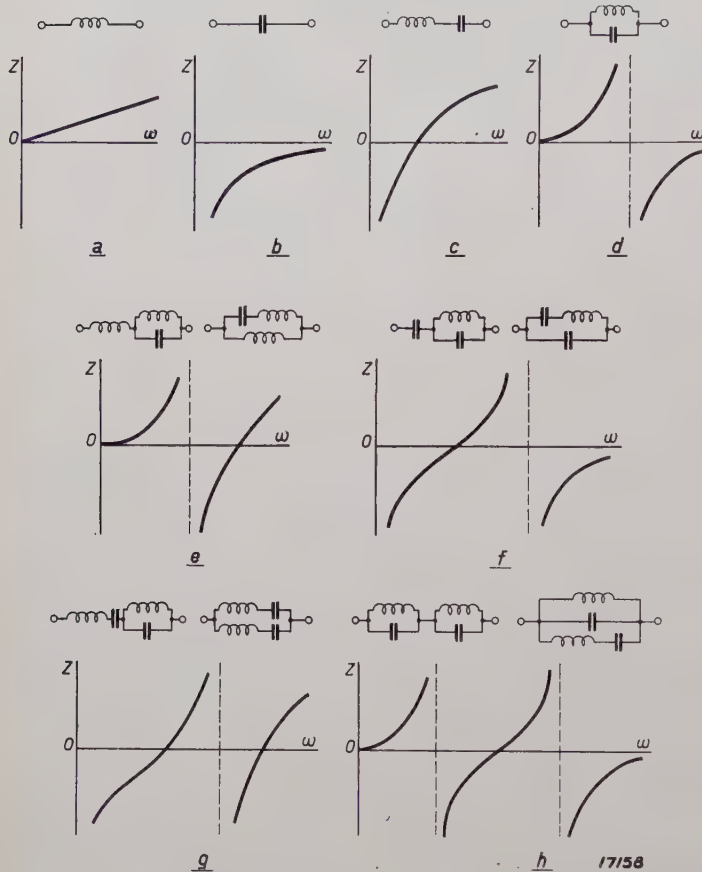


Fig. 7. Reactances composed of 1, 2, 3 or 4 elements.

A NEW APPARATUS FOR TESTING THE FASTNESS-TO-LIGHT OF MATERIALS

By J. F. H. CUSTERS.

Summary. A testing device is described, which allows to investigate the fastness-to-light of materials by means of a short time exposure.

Introduction

The colour of no substance is absolutely fast to light, and experience teaches that sunlight affects every material to a more or less extent, causing a permanent photochemical change in the colour and frequently also some change in the fibrous structure. The changes produced differ from material to material, both as regards intensity and nature. Some materials become lighter in colour, others darker, while again others acquire a colour totally different to their original colour. An instructive example of decoloration was observed by the author in a tobacconist's window display, where a dark chocolate-brown packing had been converted to a greenish colour. On prolonged illumination the chocolate-brown paper became gradually changed to a very stable bright grass green.

How can the stability of a substance against the action of light be tested and how can the fastness-to-light be standardised? Where information of the fastness of a colour or material under the action of sunlight and daylight is required, a suitable method of determining this appears to be the exposure of a sample of the material to sunlight to observe if after a time an appreciable change in colour is obtained. To arrive at standards of fastness-to-light it is further necessary to know the variation in intensity of the radiation falling on the sample of material during its period of exposure, since the intensity of illumination is not constant. In addition to changes in the altitude of the sun (diurnal and annual motion of the sun), there are also changes in intensity due to the very pronounced fluctuations in the meteorological conditions of the earth's atmosphere. In the course of an investigation the cloud conditions are liable to vary very considerably; but even without this change the intensity also varies owing to the state of humidity of the atmosphere. The spectral composition of solar radiation is itself subject to fluctuation, thus during the winter sunlight contains much less short-wave ultra-violet rays than summer sunlight, and finally the composition of direct sunlight differs appreciably from that of indirect daylight, where again the cloud conditions play an important part. These fluctuations can be

taken into account by recording with a suitable instrument (photo-electric cell or thermopile) the solar intensity during the exposure of the sample and expressing the quantity of light found in this way in terms of a standard unit, for instance the amount of light which falls on unit surface of the sample in unit time on a bright cloudless summer day. It is, however, then tacitly assumed that the relative spectral energy distribution of the light falling on the material remains constant. On the basis of a method of test worked out on these lines, fastness-to-light standards could be evolved by defining various fastness-to-light classes, each corresponding to a specific number of the arbitrary standard units of light quantity.

This method of investigation is, however, very cumbersome and tedious, especially when carrying out fastness-to-light tests during the winter months. It is evident that simpler means must be evolved, and to some extent this need has been met. The methods arrived at are of two types. On the one hand, endeavours have been made to avoid the inconvenience already referred to, by starting with a series of type colours each of which represents a specific fastness-to-light class; the sample under investigation is then compared with this standard series. On the other hand, an artificial source of light has been evolved as a substitute for natural sunlight, which has usually a constant intensity and with which the given sample is illuminated either with or without simultaneous exposure of standard type colours. The principal requirement which this artificial light source has to meet is that the light emitted must have exactly the same relative spectral energy distribution as sunlight. It is sufficient merely to point out that a low-pressure mercury lamp, which is frequently employed for this purpose, is actually quite unsuitable, for it emits a line spectrum containing only a few lines, while the ultra-violet spectral lines radiated have too great an intensity.

With the artificial sources of light employed hitherto, it was a common difficulty that to obtain an appreciable change in colour in the sample irradiation had to be continued for a very long

period. In the case of the new apparatus described below this difficulty was overcome by concentrating the light from a special type of glowlamp in such a way that the sample, whose fastness-to-light was under test, could be irradiated with 50 times the intensity of sunlight. At the same time the spectral composition of the light is modified by a suitable filter so that it is closely comparable to that of sunlight.

Principle of Operation of Apparatus

The concentration of the irradiation on the sample under test is based on the property of an ellipsoid of rotation that every beam of light radiating from one focus is reflected at the surface of the ellipsoid along a line passing through the other focus. This property is utilised in the apparatus described here by placing a nearly punctiform source of light at one focus of the ellipsoid and the sample under test at the other focus.

Fig. 1 shows the energy distribution $E(\lambda)$ of the light from the glowlamp as a function of the wave

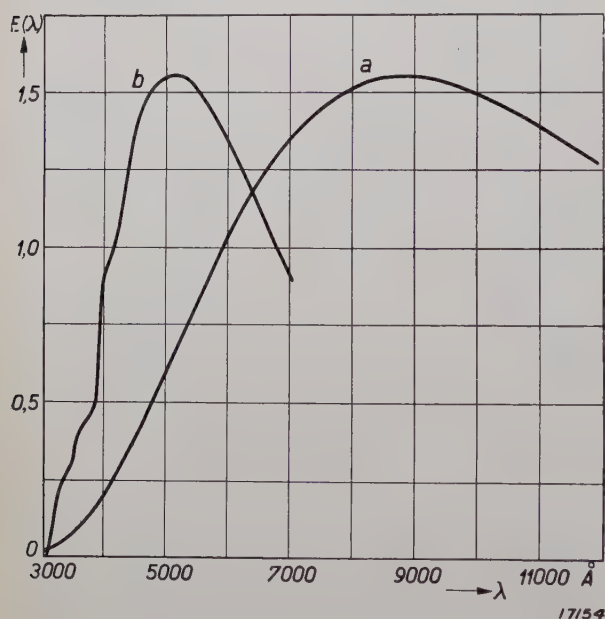


Fig. 1. Spectral energy distribution curves:
a) Glowlamp light.
b) Solar light.

length in λ (curve *a*). The light source is a 750-watt gas-filled tungsten filament lamp, burning at a temperature of 3100 deg. K. at which it emits a total luminous flux of 20 000 lumens and has a life of approximately 100 hours. For purposes of comparison the energy distribution in sunlight is also given (curve *b*).

It is seen that the two curves of energy distribution differ considerably. By means of suitable filters they can however be made comparable.

The transmission factor of an ideal filter for this purpose would at every wave length be proportional to the ratio of $E(\lambda)$ for the sun and the glowlamp. In the present case, there is the additional important requirement to be met that the filter itself must be perfectly stable to the action of light, so that very few materials can be used as filters. An aqueous solution of copper sulphate of a certain concentration satisfies these two essential requirements very well, as may be seen from the following. Fig. 2 shows the spectral transmission curve of a quartz vessel filled with a filter liquid of this type.

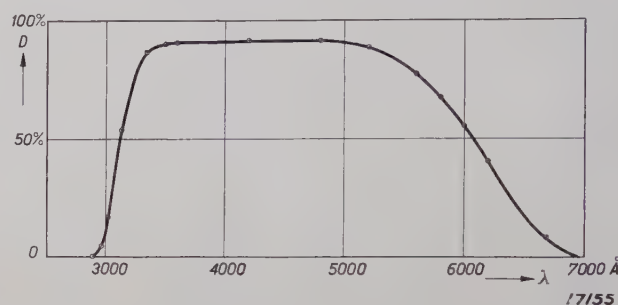


Fig. 2. Spectral transmission curves for a copper sulphate filter. Together with curve *a* in fig. 1 this curve shows that the filter absorbs a considerable portion of glowlamp light.

This filter is placed near the focus so that the radiation incident on the sample passes through the filter and is thus partially absorbed. The absorbed portion is quite considerable, as may be gathered from a comparison of fig. 1 (curve *a*) and fig. 2, since all radiation emitted from the glowlamp with a wave length above approx. 7000 Å — and this is more than 85 per cent of the total energy radiated — is absorbed by the filter and converted to heat. As a result there is a marked temperature rise in the filter vessel, which must be avoided in some way or other, e.g. by filtering out the long-wave energy before the light reaches the filter vessel. A column of water of suitable thickness is very useful for this purpose, as shown by fig. 3 which gives the spectral transmission curves for water columns 1 cm and 27 cm thick.

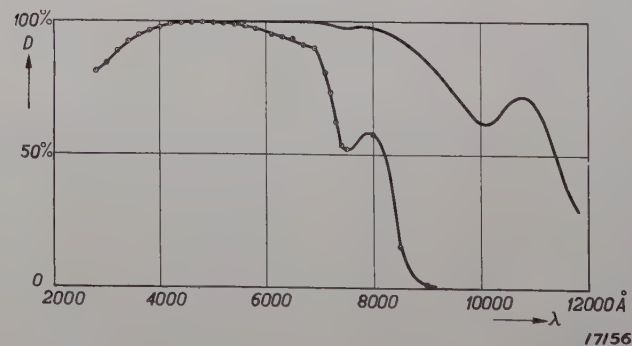


Fig. 3. Spectral transmission curves for water columns 1 and 27 cm thick.

The second curve applies to the method employed here, for in the practical design adopted for the apparatus the whole ellipsoid is filled with pure water. The dimensions of the ellipsoid are so chosen that the path traversed by the light rays from focus to focus via the surface of the ellipsoid is 27 cm. It may be seen from the figure that pure water is transparent for all rays from 3000 to 7000 Å, while above 9000 Å all the incident rays are absorbed. The light energy absorbed by the water is indeed so great that special provision has to be made for dissipating the heat evolved; details of the method adopted are given below. Fig. 4 shows the energy distribution in the plain glowlamp light (1), in the

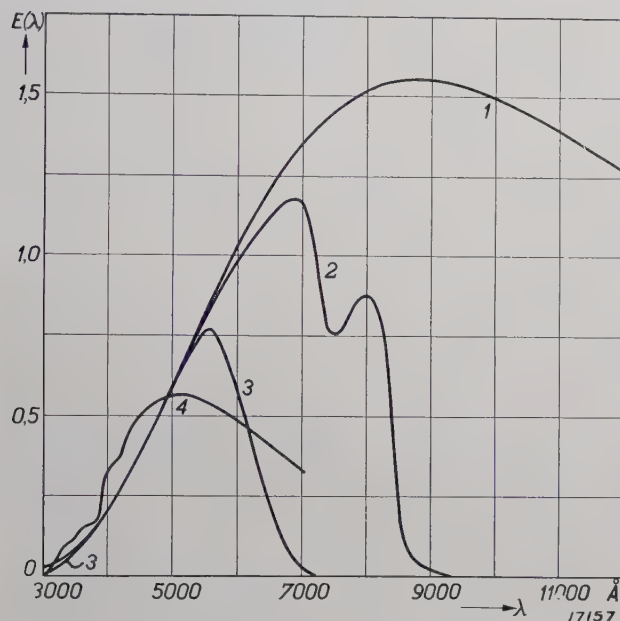


Fig. 4. Distribution of spectral energy in glowlamp light: 1) In plain lamp, 2) After the light has been passed through 27 cm of water, and 3) After it has also been passed through the second filter, 4) Energy distribution in sunlight (for comparison with curve 3).

light after passing through the column of water (2), and after being passed through the second (copper sulphate solution) filter (3), as well as that in the sunlight which reaches the earth (4). It is seen that there is very good agreement between the relative spectral energy distributions in sunlight and the light issuing from the apparatus under discussion. The deviation is greatest at wave-lengths above approximately 6000 Å. In this wave-length range the photochemical effect of the light is however so small that this difference may be neglected. It has been shown by investigations made by Rein¹⁾ that the photochemical changes observed in materials are due principally to the visible radiation with very

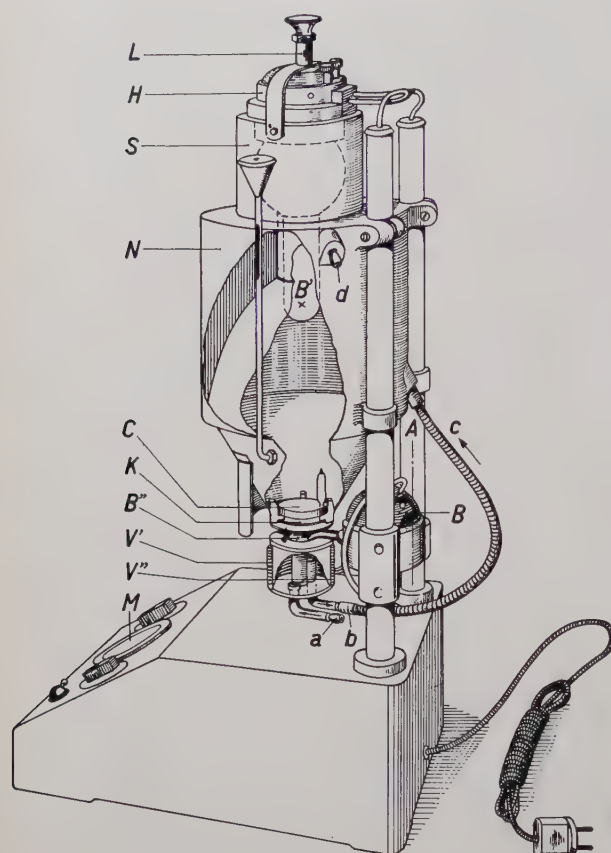
high energy. By comparative illumination experiments of objects through quartz glass (complete exposure to solar radiation) and through window glass (elimination of wave range below approx. 3250 Å) Rein showed that contrary to common opinion the short ultra-violet of sunlight contributes only very little to the action of sunlight on all kinds of coloured materials. It depends entirely on the absorption spectrum of the material under investigation which range of wave-lengths causes the most marked decoloration. White and yellow pigments (e.g. white or undyed textiles or dyes, white paper, films, etc.) which absorb ultra-violet light exclusively and whose absorption usually increases with diminishing wave length, exhibit very marked differences on illumination through quartz glass and window glass. It is therefore desirable for the artificial light source to contain wave-lengths down to 3000 Å. Coloured materials not only absorb in the ultra-violet, but also a considerable proportion of waves in the visible part of the spectrum, and since the sun is richest in just these rays the photochemical action of sunlight is particularly due to this range of wave lengths.

Construction of Apparatus

The general construction of the apparatus evolved is shown in fig. 5. Owing to the difficulties encountered in the construction of a complete ellipsoid, only the upper half of the ellipsoid has been employed and fitted at the top with a neck. The lower side consists of a conical jacket which at the bottom is closed by a quartz plate K. On the interior the ellipsoid is bright chromium-plated. The coefficient of reflection of chromium for vertically incident light varies in the wave-length range in question here (from 3000 to 7500 Å) from 62 to 71 per cent. Since the greater part of the light from the glowlamp strikes the surface at a fairly flat angle, the average coefficient of reflection is in fact much greater. The ellipsoid and the cone are filled with water up to the edge of the neck. The incandescent filament of the lamp is situated at the focus B', this lamp being made from a specific kind of glass to prevent the immersed part of the bulb from cracking. The liquid filter vessel is located at C and is also immersed in the water filling the ellipsoid, for in spite of preliminary filtering through water so much heat is still generated in C that if the vessel were placed in air it would crack. In the arrangement adopted here, the heat developed in C is absorbed by the water. To provide additional means for the dissipation of the heat, the ellipsoid

¹⁾ H. Rein, Z. angew. Chem. 47, 157, 1934.

has been fitted with a cooling jacket *N* connected to a water tap at *c*; *d* is the outlet for the cooling water. The sample of material irradiated is located



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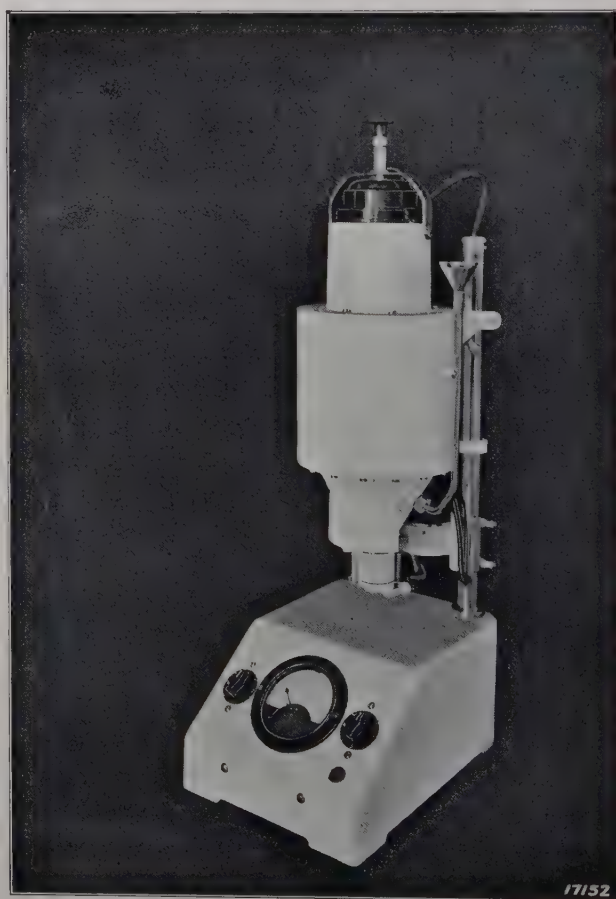
Fig. 5. Construction of the fastness-to-light meter. *B'* is the incandescent filament of the lamp situated at one focus of the ellipsoid. The glowlamp is always accurately positioned at the focus *B'* as it is secured to the holder *H* by a positioning flange. *C* is the copper sulphate filter. The sample under test is placed at the other focus *B''* and is fixed to a turntable holder; it can be cooled by the electric blower *B*.

at the focus *B''* which is slightly below *K*. The sample is clamped to a metal holder under a circular diaphragm 15 mm in diameter (for which springs *V'* and *V''* have been provided), so that one part is exposed to radiation and the other part is screened. In spite of the extensive measures taken to absorb the long-wave energy in the two light filters supplementary cooling of the sampling has been found necessary in some cases. This is indeed not surprising when it is remembered that the effective intensity of illumination of the sample is about 50 times the intensity of sunlight. A considerable proportion of the light falling on the sample is converted to heat and to dissipate this heat energy cooling water is circulated through the centre of the sample holder and flows out through *b*, entering the cooling jacket *N* at *c*. In this way an excessive temperature rise at the sample is effectively avoided, provided that the material

itself is a good conductor of heat (or is sufficiently thin) and a heat conducting path is established with the metal holder. If this cannot be achieved, as with woollen or rough materials which are able to accumulate warm air between the fibres, cooling from above is essential, and is provided by a rapid current of air directed by the electric blower *B* against the surface of the material.

In regard to the fixing of the light source it should be mentioned that the glowlamp is fitted with a so-called positioning flange with which the lamp is secured in the holder *H* in an invariable position; the holder *H* rests against the head *S* and is secured with the clip *L*. The incandescent filament of the lamp is thus always brought exactly into the focus of the ellipsoid. A mains-fed transformer is employed for feeding the lamp and motor and is accommodated in the foot of the apparatus. The current consumption of the lamp is indicated on the ammeter *M* and can be regulated by means of two switches. A general view of the whole apparatus is shown in *fig. 6*, while *fig. 7* shows the rotary plate holder for the sample of material under test.

Although tungsten, which volatilises during the running of the lamp, rapidly blackens the lamp



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Fig. 6. General view of fastness-to-light meter. The total height of the apparatus is approx. 85 cm.

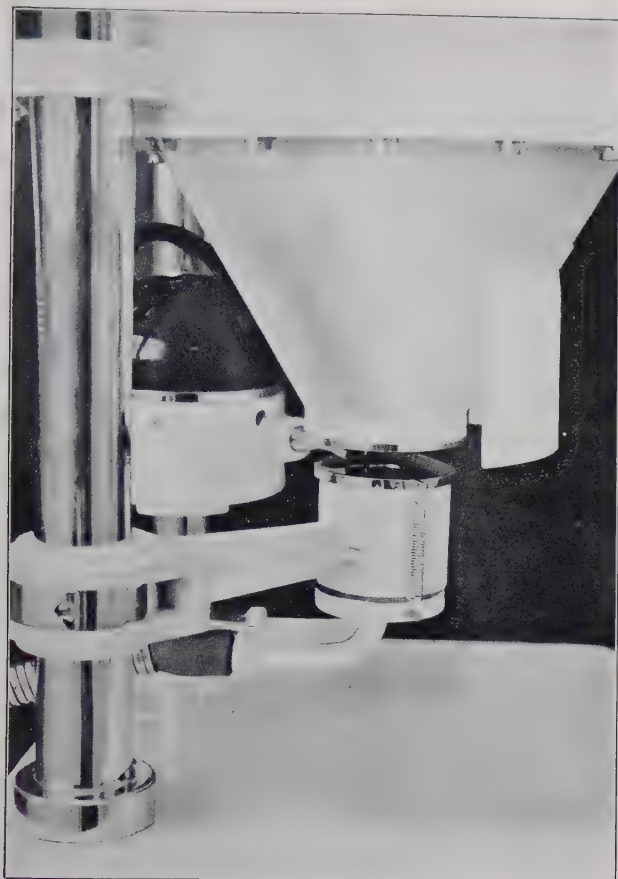


Fig. 7. View of the lower side of the meter showing the turntable holder for the sample under test and the fan with blower hood for cooling the sample when necessary.

bulb the surface round the incandescent filament remains perfectly clear in view of the special design of the lamp adopted. The luminous flux of the apparatus is thus maintained constant throughout the life of the lamp.

Results of Investigations with the New Apparatus

Apart from extensive experiments carried out to determine the comparative illumination intensities of the apparatus and the sun, a series of comparative tests were also made with a variety of samples of material. Thus 30 kinds of offset printed colours of different shades and degrees of fastness-to-light were irradiated, every colour showing the same degree and type of fading after 30 minutes exposure in the apparatus as obtained with exposure to sunlight for a period of eight sunny days in September. The yellowing of various kinds of white paper was found to be exactly the same in this apparatus as on irradiation by sunlight; the normal colour of newsprint was altered after two hours illumination to a yellowish brown. Coloured samples of paper with a low fastness-to-light exhibited a marked fading already after three

minutes irradiation, while after 30 minutes they had been completely bleached.

Samples of textile materials were also tested. An apt example is the series of standard blues already referred to, which under the fastness-to-light meter became decoloured in the same way and in the same order as when exposed to solar radiation. This series contained eight examples, numbered from I to VIII, the fastness-to-light coefficient increasing from I to VIII. No. I exhibited a distinct decoloration already after three minutes exposure in the meter, and No. V a just detectible change after an hour's exposure. If a textile material shows no distinct decoloration, after one hour's exposure it appears to be adequately fast to light.

Owing to the variety of practical requirements which have to be met, the time of exposure to light which a sample must be able to sustain without decoloration varies according to the nature of the sample. In the case of textiles it is reasonable to prescribe a minimum period of exposure of at least an hour, for printed colours (black and other colours) on paper at least half an hour, and for varnished colours at least two hours before a change in colour takes place.

With certain textiles a striking behaviour was observed. On exposure to irradiation they became darker and during a subsequent period of non-irradiation they regained their original colours almost completely, only a slight residual change being detectible. Owing to the weak intensity of sunlight this behaviour is barely or not at all visible under normal conditions (many lithopones), since the material has an opportunity to recover. Actually after suitable solar irradiation the residual effect alone is observed. In general, only materials with a pronounced fastness-to-light exhibited this reversible behaviour in tests with the apparatus. In practice the same standards can be retained here as adopted for materials showing a normal behaviour; after irradiation a short period must be allowed to elapse to see whether the darkening in colour disappears or not.

In conclusion, reference must be made to the possibility of using the apparatus described for formulating fastness-to-light standards. To standardise this property in terms of solar exposure hours has very little practical value. Since the apparatus described here permits a constant intensity of irradiation to be maintained, and according to experience produces the same fading as the sun, it offers a standard illumination for use in fastness-to-light tests.

FESTIVE ILLUMINATION OF THE NETHERLANDS CRUISER "DE RUYTER"

For visits in foreign harbours this new cruiser has been equipped with an installation by means of which the entire vessel can be brightly illuminated, without having to depend upon search-lights on the shore. The grey hull is lighted by 24 incandescent lamps of 500 watts in enamelled reflectors, which are hung outboard from suspension poles 20 ft. long.

The fire-control tower, which is about 65 ft. high, is illuminated by six 750-watt lamps in mirrored reflectors. The gun-turrets, the boats and other accessories are lighted separately. Altogether, 30 kilowatts have been installed for this festive illumination.

THE PERCEPTION OF COLOUR

By P. J. BOUMA.

Summary. The principles of colour vision are discussed in this article, consideration of the problem being limited to its qualitative aspects. An investigation is made of the conditions determining the production of a colour sensation. Following consideration of the effect of the nature of the incident light and the characteristics of the object illuminated, the properties of the eye are discussed. It is shown that all colour sensations or impressions can be represented graphically in a plane. The effects of very low brightness levels and of simultaneous and successive contrast are then considered, and finally brief reference is made to the theory of colour vision.

"When I look out of the window, I see that the grass is green".

We all agree with this statement, but as a rule we do not realise the vast complexity of phenomena which lead us to draw this apparently simple conclusion.

The sun illuminates the grass with light containing practically all wave-lengths of the visible spectrum in definite proportions. Of the incident light the grass reflects a certain portion, but not the same proportion of each of the various wave-lengths is reflected. A portion of the reflected light — whose spectral composition is thus different from that of the incident sunlight — impinges on the eye, penetrates into it and after refraction in the lens and liquids of the eye throws an image on the retina. The formation of this image produces certain stimuli in the optic nerves; these stimuli are transmitted to the brain and there become registered by our consciousness; the impression which we finally receive we describe briefly by the statement: "I see the grass is green".

This step by step analysis of the process of vision also teaches us the conditions determining the production of a specific colour sensation.

Effect of the Nature of the Incident Light

The nature of the light falling on the grass can differ in two particulars, viz.,

- 1) In character (spectral composition).
- 2) In quantity (intensity of illumination).

To visualise the effect which the spectral composition of the incident light has on the colours of illuminated objects, let us consider a few important practical examples:

- a) If sunlight is replaced by nearly monochromatic sodium light, then all objects are almost exclusively illuminated with wave lengths of 5890 and 5896 Å. Whatever may be the properties of reflection of the objects, they can never reflect any light other than rays of these

particular wave-lengths¹). The net result is that the same type of light impinges on the eye from every object: We see all objects as yellow, and only the "dark" objects, which reflect only a small amount of light, appear a brownish yellow. It cannot be expected that in these circumstances the grass will still appear green.

- b) In light from a mercury vapour lamp our surroundings already have a much closer resemblance to their appearance in the "world of daylight"; nevertheless it is observed that various objects exhibit an unnatural, i.e. abnormal, colour. This is mainly due to the fact that the red rays are absent in mercury light and all blue rays have been concentrated to a single wave length (4358 Å). Since the incident light has a different spectral composition to daylight, this will also be the case with the reflected light, with the net result that the colours appear different to us.
- c) Also when we use the light from ordinary electric glowlamps our surroundings will again appear different to what we see in daylight. That the difference in this case is less striking is partly due to the fact that we have become more accustomed to this type of light, and partly because the light from a glowlamp with its continuous spectrum differs much less from sunlight than, for instance, sodium and mercury light. Very striking are, however, the differences when we view the same surroundings in quick succession in daylight and glowlamp light, or when a sheet of paper is illuminated half with daylight and half with glowlamp light (for instance when the paper is held in

¹) We must here make an exception of the so-called fluorescent substances, i.e. chemical substances which transform incident light into light of different (longer) wave length. Thus rhodamine converts yellow sodium light into red light and is therefore employed in practice for making traffic signals (boards) appear red on sodium illumination.

front of a gap in the curtains in a room from which daylight is excluded, and the two halves are separated by another sheet of paper fixed perpendicular to them). In this case the half sheet illuminated with daylight will appear slightly bluish and the other half a pale orange yellow²⁾.

These examples show clearly that colour is not a property of the objects themselves but a result of the combination of the source of light, the object viewed and the eye.

If the spectral composition of the light is left unchanged, we can vary the amount of the incident light (intensity of illumination) and hence also the quantity of the reflected light (brightness of the object) within wide limits, without observing a marked alteration in the nature of the colour sensations produced by the objects viewed: Grass will appear green both on a bright sunny day and in dull weather. Only when the objects have very low brightness values (e.g. in a moonlight landscape) will the brightness have an appreciable effect on the nature of the colour. We shall return later to a discussion of this point in greater detail.

Effect of the Characteristics of the Object

The yellow flower which grows among the grass receives exactly the same sunlight, but reflects different proportions of the various wavelengths than those reflected by the grass. As a result the light from the flower which impinges on the eye has a different spectral composition to the light coming from the grass. Owing to the specific characteristics of the eye we perceive this difference in composition as a difference in colour: the flower appears yellow, and the grass appears green.

The part played by the object in producing a colour sensation consists therefore exclusively in the fact that it reflects a specific portion $R(\lambda)$ from light of a particular wavelength λ . If $E(\lambda)$ is the spectral composition of the incident light, then the spectral composition of the reflected light is $R(\lambda) \cdot E(\lambda)$.

If R is the same for all wave lengths, the reflected light will have the same spectral composition as the incident light and will also produce the same colour sensation (provided R is not too small). Viewed in daylight such an object will appear white (or grey if R is small), and it is usual therefore to speak in this case of a "white object", although the same object viewed in sodium light will naturally appear to be yellow.

If R is not the same value for all wave lengths, the reflected light will have a different composition to the incident light. In daylight such an object will then usually not appear to be white, and in this case we generally ascribe a specific colour to the object, although with another kind of incident light it will as a rule produce a different colour sensation (in certain circumstances even appearing to be white).

The "Normal" Mixing Characteristics of the Eye

The "Visual organ"³⁾ acts simultaneously as a receiver, transformer and reproducer for colours and thus constitutes the most complex link in the chain of generating a colour sensation.

We shall first summarise briefly the various problems entailed here.

- 1) How does the eye operate as a mixer for rays of different wavelength, i.e. what colour sensations do the various spectral mixtures produce which can impinge on the eye?
- 2) How do these characteristics change with very small brightness values?
- 3) How is the eye's ability to discriminate colours affected by the simultaneous presence of objects of different colour in the field of vision?
- 4) Are the characteristics of the eye affected by light sensations to which it is exposed just previously to viewing a particular object?
- 5) What individual variations occur in the "colour characteristics" of the eye?

To obtain an insight into the first problem, consider the four other influences as absent, i.e. an object with a brightness above a certain limit (about 3 candles per sq. m) is viewed with a non tired normal eye, no objects of another colour being present in the field of vision. For these conditions let us determine the various colour sensations corresponding to different spectral compositions of the light incident on the eye⁴⁾.

Each specific spectral distribution produces a definite colour sensation in the eye. Is the converse also true? Can we deduce the spectral composition of the light from the nature of the colour sensation obtained? This question must be answered in the negative. A specific colour sensation can be produced by entirely different spectral compositions.

³⁾ "Visual organ" is defined as the combination of the eye proper, the optic nerve and that part of the brain which assists in creating a colour impression. The term "eye" is usually also defined in this broad sense, for of many phenomena in vision we are unable to determine in which part of the organ they actually take place.

⁴⁾ Consideration is omitted here of whether the light which impinges on the eye is derived directly from the light source or is first reflected by an object.

²⁾ The difference is emphasised here by simultaneous contrast, which is referred to in greater detail below.

The well-known phenomenon of complementary colours should be recalled: A combination of two spectral colours (e.g. blue 4800 Å and yellow 5800 Å) can produce exactly the same colour impression as the continuous solar spectrum.

In the same way as we have here simulated the colour of sunlight by mixing two colours of the spectrum, it has been found possible by suitably mixing three spectral colours (e.g. red 7000 Å, green 5200 Å and blue 4800 Å) to obtain practically all compound colours⁵).

An interesting survey of these mixtures is afforded by a graph in which every colour sensation is indicated by a specific point on the plane of the paper. In *fig. 1* the three primary colours of the spectrum mentioned above are indicated by the points 1, 2 and 3. To represent other colour sensations in the

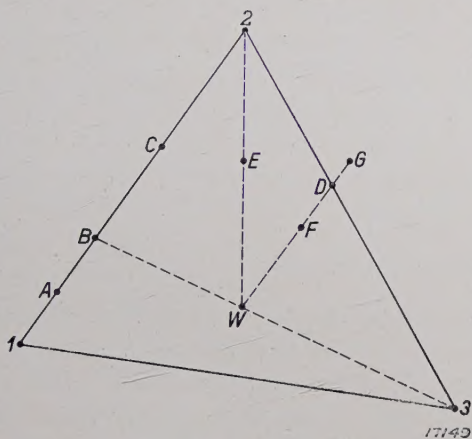


Fig. 1 — Mixing of colours from three primary colours: 1) Red 7000 Å; 2) green 5200 Å; 3) blue 4800 Å. W represents white; A, B, C, D are orange, yellow, yellowish-green and bluish-green respectively; the line 1—3 embraces the shades of purple. G represents the spectral blue-green, which must be mixed with white (W) in order to give the blue-green D. E is produced by mixing W and 2.

diagram the mixture of two colours be represented by the points in the line joining the two points for these colours. We thus get the line 1—2 for all colour sensations which can be simulated by a suitable mixture of 1 and 2. The position of the mixture on the line is determined by the ratio

in which we must mix the two components; the greater the percentage of colour 1 required the closer will be the point to 1 which represents this colour⁶). To determine the position of a particular colour, e.g. white, we must first assume a mixture of the requisite amounts of 1 and 2. This mixture is represented by the point B. White is now produced by a suitable mixing of B and 3 (B is thus a complementary colour to 3). The point W is therefore on the line B—3, its position on this line being determined by the ratio of B and 3 in the mixture. In this way every colour sensation which can be produced by a mixing of the three primary colours can be represented by a point within the triangle 1-2-3. What are now the relative positions of the various colours in this triangle?

The mixtures of 1 and 2 are: orange (A), yellow (B) and yellowish green (C). Along the line 2-3 the various shades of bluish-green (e.g. D) are situated, while along the line 1-3 are the different shades of purple. From the method of representing the colour mixtures adopted here it follows that two colours are complementary when the point W lies on the line joining them. The pair of colours B-3 is an example of this. Furthermore we see that the colour sensation E can be simulated by mixing spectral green (2) with white (W); this mixture produces a sensation of an “unsaturated” (pale, bleached, dull) green. The closer this point E is moved towards 2 the deeper will be the colour, finally reaching its maximum saturation at 2.

If the point F is moved along the line WD a progressive intensification in the bluish-green colour is similarly observed, but contrary to the previous example the maximum saturation is not yet reached at D. For among the spectral colours there is still a deeper bluish-green, which must be mixed with a certain amount of white (bleached) in order to give the point D. Thus in our method of representing mixed colours we must represent this spectral bluish-green by a point G on the line W-D produced: The point D must be situated between W and G.

Similar considerations apply to all spectral colours, and these are all (with the exception of 1, 2 and 3) represented by points outside the triangle 1-2-3.

In *fig. 2* the same triangle 1-2-3 has again been drawn but with the spectral colours included. The numbers relate to the wave lengths. If we also draw the line 1-V, connecting the two ends of the

⁵) The type mixture referred to here must not in any way be confused with the mixing of dyes which follows entirely different laws. The two methods of mixing are fundamentally different: In the first case one type of light is mixed with another, both being allowed to fall on the eye simultaneously or with the aid of a sector disk being thrown into the field of vision in rapid succession, whilst in the second case each of the two dyes absorbs a specific proportion of the incident light. The results achieved by these two forms of mixing are also quite different: If yellow and blue are mixed by the sector method they will give, as complementary colours, white or grey on a correct choice of the ratio. But if a blue dye is mixed with a yellow dye, the former will absorb red and yellow rays and the latter the blue rays of solar light, so that a green colour is left.

⁶) Quantitative scales can be always so chosen that the method of representation never results in contradictions. The quantitative side of the problem will be discussed in a later article.

The colour sensation is also affected in quite another way by the surrounding conditions. The reader will have noticed that in discussing the colour triangle no mention was made of grey and brown. As already pointed out the impression of "grey" is obtained when the object being viewed emits the same type of light as a "white" object, although having at the same time a low coefficient of reflection. Grey is thus really the same as white, in the sense that a white object in general has a brightness higher than that of its surroundings and a grey object a lower brightness: As a result of simultaneous contrast the surroundings make white appear grey. If a white paper and a grey paper are separately illuminated in dark surroundings, the grey e.g. receiving about five times more light, it is quite readily possible to make the two sheets appear to have exactly the same colour.

In the same way as grey may be produced from white by simultaneous contrast, brown may be obtained from yellow, orange or red. This can also be demonstrated by a similar experiment. To a lesser extent the same phenomenon occurs with green, and at low coefficients of reflection the so-called olive green is produced.

Finally, it should be pointed out that simultaneous contrast in the same way as it intensifies colour differences also emphasises differences in brightness: A small white spot in a large black field appears much brighter than the same white in a large white field.

Successive Contrast

By successive contrast we understand the effect of a prior illumination of the eye on the subsequent differentiation of colour. These phenomena are of a similar type to simultaneous contrast: When the eye has become accustomed for some time to a sodium light a white light will again appear to be bluish.

If the intensity of prior illumination were very powerful (we have for instance looked directly at a lamp for a time), this phenomenon will result in the appearance of an after-image; For a brief period an image of the object previously viewed will persist, sometimes dark and sometimes bright against the background and frequently with quite different colours than possessed by the original object. Such after-images are very disturbing to vision and play an important part in glare problems.

Theory of Colour Vision

Only brief reference will be made to this subject; as it is beyond the prescribed scope of this Review.

Moreover, as yet very little definite information has been gathered of the mechanism of colour vision.

The study of the phenomena of colour vision has led to the enunciation of two different sets of theories, which subsequently have become expanded in a variety of directions.

The first, due originally to Young and Helmholtz, assumes that three sensations can take place in the eye; the first sensation is excited to the greatest extent by red light, the second by green light and the third by blue light. On the basis of this assumption the mixing laws established experimentally are readily explained: each colour provides a stimulus for the three fundamental sensations in a specific ratio, and it can thus be actually expressed by the ratio of these magnitudes. With this theory we can moreover readily account for the occurrence of different types of colour blindness on the simple assumption that in these one or other of the three fundamental sensations is absent.

The other theories, due initially to Hering, assume three sensations each of which can take place in two directions: A blue-yellow sensation, a red-green sensation and a black-white sensation; blue light displaces the first sensation in the one direction and yellow light displaces it in the opposite direction, etc. A theory on these lines gives us a better insight into the sensations experienced with simultaneous and successive contrast, after-images and fatigue phenomena, etc., but does not give such a natural and simple explanation of the representation of colours in a colour triangle as is offered by the Helmholtz theory.

It has hitherto not been possible to demonstrate anatomically that three kinds of nervous elements exist in the retina or that three kinds of chemical phenomena take place there.

In conclusion a few words may be added regarding binocular colour mixing. If the two eyes are exposed to light of different colours, a mixed colour is obtained with most persons, the same mixing rules applying in general to this sensation as to ordinary mixing. With other persons such a mixture cannot be obtained and as a rule these will see only one of the two original colours. From the existence of binocular mixing it may be concluded that the mixing processes — at least the combination of the primary colours to give a simple colour sensation — do not take place on the retina or the optic nerve, but at some deeper point, possibly not before the brain is reached.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1093: A. E. van Arkel, E. J. W. Verwey and M. G. van Bruggen: Ferrites I (Rec. Trav. chim. Pays-Bas, **55**, 331-339, May, 1936).

Radiographs were made of mixtures of oxides of bivalent metals (MO) with ferric oxide (Fe_2O_3) in different proportions, which had been strongly heated from 1200 °C up to 1300 °C. for several hours. The radiographs indicated that mixtures containing a high percentage of Fe_2O_3 have comparable structures. At high temperatures (up to 1300°C.) the ferrite phase (with spinel structure) stretches far towards the Fe_2O_3 side. At lower temperatures (800° to 1000 °C) this area is considerably contracted. From a crystallographic standpoint, solid solutions in which the iron content is greater than corresponding to the ratio MO: $\text{Fe}_2\text{O}_3 = 1:1$ may be regarded as "differential phases" as defined by Hägg. Compounds with a composition 2 MO. 3 Fe_2O_3 as assumed by Hilpert do not exist.

No. 1094: E. J. W. Verwey, A. E. van Arkel and M. G. van Bruggen: Ferrites II (Rec. Trav. chim. Pays-Bas, **55**, 340-347, May, 1936).

At high temperatures (up to 1400 °C) the proportions in which ferrites are miscible with metallic oxides are investigated. Hausmannite (Mn_3O_4) dissolves considerable quantities of Fe_2O_3 (at 1300° up to $\text{Mn}_3\text{O}_4 : \text{Fe}_2\text{O}_3 = 1:6$), whereby its tetragonal lattice gradually passes over into the cubic lattice of ferrite. Solid solutions of MgO with Mg Fe_2O_4 and of NiO with Ni Fe_2O_4 , which are formed at high temperatures, segregate slowly at about 1000 °C. The elementary cell for ferrite is almost exactly double as great as that for the oxides. Segregation can therefore be investigated by X-ray methods only on the basis of calculated and observed intensities of the diffraction lines. Magnetic measurements reveal the segregation far more accurately than X-ray measurements, and the latter much better than observations with the microscope.

With a ratio of CuO: $\text{Fe}_2\text{O}_3 = 3:1$ a new compound is formed in copper ferrite.

No. 1095: J. H. de Boer and J. D. Fast: The α - β transition in zirconium in the

presence of hydrogen (Rec. Trac. chim. Pays-Bas, **55**, 350-356, May, 1936).

Both α and β zirconium absorb hydrogen. The solubility decreases in both modifications with rising temperature. Hydrogen is absorbed when α zirconium is converted into β zirconium at rising temperature and in a hydrogen atmosphere. On cooling β zirconium passes over into the α modification and at the same time liberates hydrogen. The transition of α zirconium into the β modification appears to be responsible for the very rapid absorption of hydrogen observed by Clausen and Ludwig when a zirconium wire is allowed to cool.

No. 1096: A. G. Boer, E. H. Reerink, A. v. Wijk and J. v. Niekerk: A naturally occurring chicken provitamin-D (Proc. Roy. Soc. Amst., **39**, 622-632 May, 1936).

This paper describes the preparation and properties of provitamin-D which is a constituent of cholesterol. The probable structural formula deduced from various data is confirmed by different reactions and proved by comparison with pure synthetic 7-dehydrocholesterol with which the new provitamin D is identical. By irradiation a vitamin D is obtained whose anti-rachitic action on chickens is comparable with vitamin D from cod-liver oil.

No. 1097: W. Uyterhoeven and C. Verburg: Température des électrons (T_e) dans une décharge en colonne positive dans un mélange Ne-Na (C.R. Acad. Sci., Paris, **202**, 1498-1500, May, 1936).

In a previous paper (see Abstract No. 1047) the authors have indicated that the addition of a little sodium vapour to neon causes the voltage drop in the positive column to increase considerably. In the present paper probe measurements in a column of Ne-Na are described. The temperature of the electrons (T_e) and the concentration of the ions (n_p) are determined as a function of the temperature of the wall of the tube, i.e. as a function of the Na concentration. The electron temperature attains a maximum of approx. 23 000 °K. with one atom of sodium to 10 000 atoms of neon; in the case of pure neon and other conditions being equal the temperature is 19 500 °K.